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FINAL REPORT

PERIPHERAL CUES AND COLOR IN VISUAL SIMULATION

F49620-79-C-0030

By

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SUMMARY

Flight performance as affected by visual field size, scene complexity and the use of color was measured in a Boeing 747 flight simulator. The visual simulator was a computer generated imagery system (G.E. Compuscene).

EXPERIMENTAL VARIABLES

Field Size

There were two viewing fields tested, both of 30° vertical extent. The smaller one was 40° horizontally, 20° to either side of the forward viewing centerline. The larger one included an additional 74° to the left, from oblique and side displays.

Scene Complexity

Two levels of complexity were studied, for convenience designated "simple" and "complex." The simple scene was a blue/black runway in a homogeneous surround. There were no markings on the runway for either level of complexity. The complex scene surround contained the details normally available in the Moses Lake, WA computer data base used for flight crew training.

Color

Three different hues were selected for the simple scene surrounds, buff, red, and blue. The red and blue were chosen because they are from opposite ends of the visible spectrum and thus most sensitive to chromatic aberration effects, especially as related to individual differences in depth perception. The buff approximated the color of sandy soil and represented a middle (neutral) area of the spectrum.

In one portion of the study where the red and blue surrounds were compared for their effects on performance, the normal colors of the complex scene were replaced with the single hue but with saturation variations corresponding to complex scene details.

EXPERIMENTAL TASKS

Experiment #1

In the first experiment pilots were required to make a 90° descending left turn of 2 NM radius, rolling out lined up with the runway on a 2.7° glide path. (The runway surround was buff in the simple scene.) The flight ended one mile after the turn was to be completed. Four trials were flown to each combination of two fields of view and two levels of scene complexity for a total of 16 trials. Figure 1 shows these conditions for all three experiments.

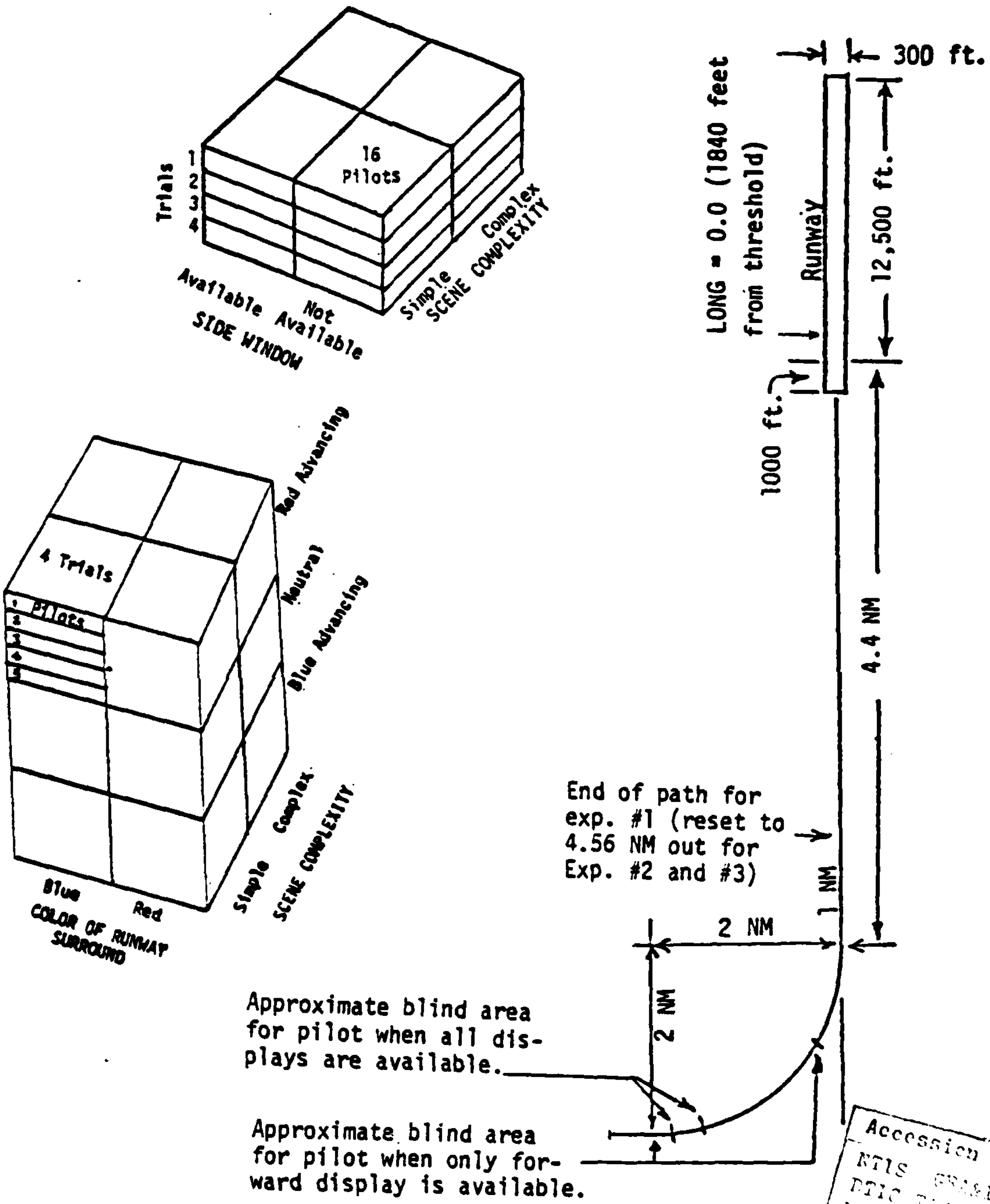

Figure 1. Diagram of experimental designs and flight paths for simulator experiments.

Experiment #2

The second experiment required straight-in approaches from 4.6 NM distance to touchdown under the same experimental conditions as those used in the first experiment.

Experiment #3

The third experiment required a straight-in approach from 4.6 NM to touchdown, the same as in the second experiment. There were two levels of scene complexity as in the first and second experiments, but instead of two fields of view, there were two surround colors, red and blue. The single field of view used in the third experiment was 114° in horizontal extend, i.e., 132° with an 18° gap between the oblique and side displays.

EXPERIMENTAL SUBJECTS

The group of military pilots who served in the study were all current in the C-141 military air transport but had no experience in piloting the 747. They were selected on the basis of tests for chromostereopsis, i.e., tendencies to see hues from one end of the visible spectrum as being closer than those from the other end. Three groups were thus obtained, one which saw blue as being nearer than red, one which saw red nearer than blue, and one which had no tendency in either direction. This division was made because of the third experiment, though the same pilots served also in the other two (with minor exceptions).

In the first two experiments 16 pilots were used. In the third there were 15 pilots, five in each chromostereopsis group. All were given a brief period of training in the operation and handling characteristics of the 747. The training pilot was from the staff of instructor pilots currently working in that capacity for the Boeing Commercial Airplane Company.

DEPENDENT MEASURES

Flight parameters such as aircraft attitude, flight path deviations, velocities, and touchdown descriptors were used as indicators of the effects of the independent variables on pilot performance. The data set from which selection was made for statistical analysis contained sixteen measures, though not all were applicable in each of the three experiments. Dependence on visual flight was ensured by removal (occluding, etc.) of instrumentation regarding altitude, vertical velocity, glideslope deviation, and azimuth.

RESULTS

Experiment #1

In the first experiment, where performance was sampled at three points in a descending turn, the field of view (40° vs. 114°) showed

significant effects on performance. In five cases field of view interacted significantly with scene complexity. Altitude, for example, was closer to being correct at the end of the turn with the wide field of view when the scene was complex, but when the scene was simple the mean for this measure was more nearly correct with the narrow field of view.

The pilots tended to make tighter turns (Figure 2) when the field of view was narrow, presumably because they wanted to get sight of the runway sooner. This tendency was reflected in higher roll angles and heading change rates. Vertical and lateral deviations from glideslope were more scattered with the small field of view (Figure 3). The ellipses shown in the figure represent two dots from glideslope in either dimension. Using the electronic instrument landing systems acceptance area as an operational requirement these data suggest that the 114° field of view and the complex scene must be combined to achieve an acceptable lateral deviation. Ninety-seven percent of the trials were within the lateral acceptance angle under the 114° field of view and complex scene condition. Even the complex scene does not provide sufficient visual information for the pilots to achieve a satisfactory altitude (maximum = 28%) at the outer marker. More information in the visual scene may be required, if we assume that pilots can visually judge 1330 ± 420 feet with a perceptually rich ground plane. Performance generally improved over the first three of the four trials under a given treatment combination, dropping off on the last trial.

Experiment #2

The conditions of the second experiment were the same as the first except that the task was a straight-in approach and touchdown. In this experiment, in addition to field of view, scene complexity, and trial order, distance from ILS touchdown point was introduced as an independent variable; data were sampled at 12 thousand, 6 thousand, and 3 thousand feet from the touchdown point as well as at touchdown.

As expected, distance was shown to be significant in its effect on many of the performance variables, e.g., altitude, vertical velocity, pitch angle, or power on the engines. Distance also exerted its effect as an interaction with other independent variables such as scene complexity (Figure 4). In two instances, it is shown to interact with both scene complexity and trial order, on vertical velocity and pitch angle.

Field of view was significant almost solely as an interaction with one of the other independent variables. Trial order varied in its effect on performance but not in a regular or logical way as in the first experiment. In only one analysis, vertical velocity, did trial order show significance as a main effect. Scene complexity was an aid to glideslope adherence, improving as distance from touchdown decreased.

Touchdown performance data showed significance for only two dependent variables, lateral displacement from the runway centerline and rate of change in pitch angle. Scene complexity as a main effect influenced lateral displacement on touchdown and interacted with trial order in its effect on pitch angle change rate.

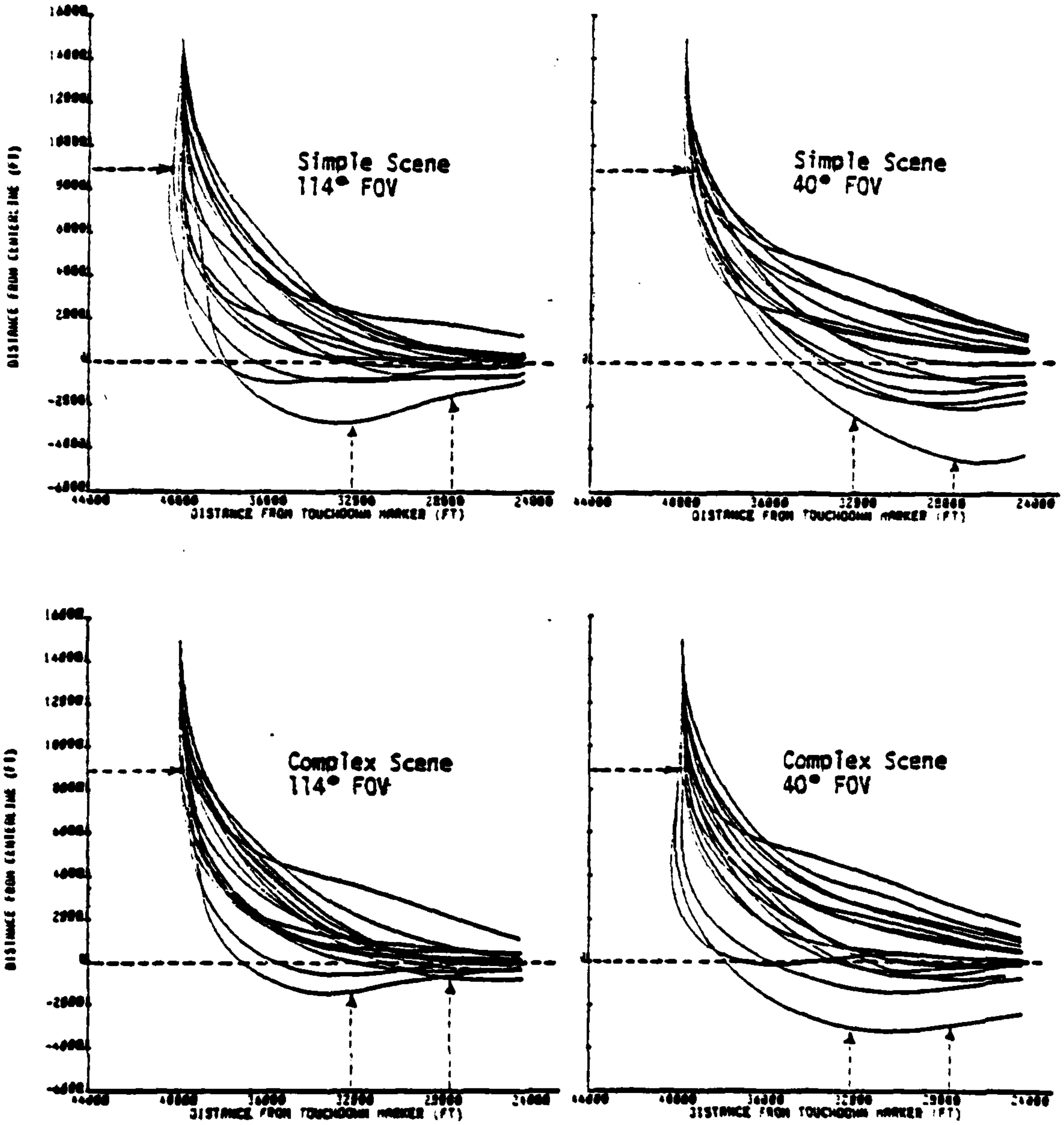

Figure 2. Flight paths flown by 16 pilots in 747 simulator on trial #2 of four conditions of Experiment #1.

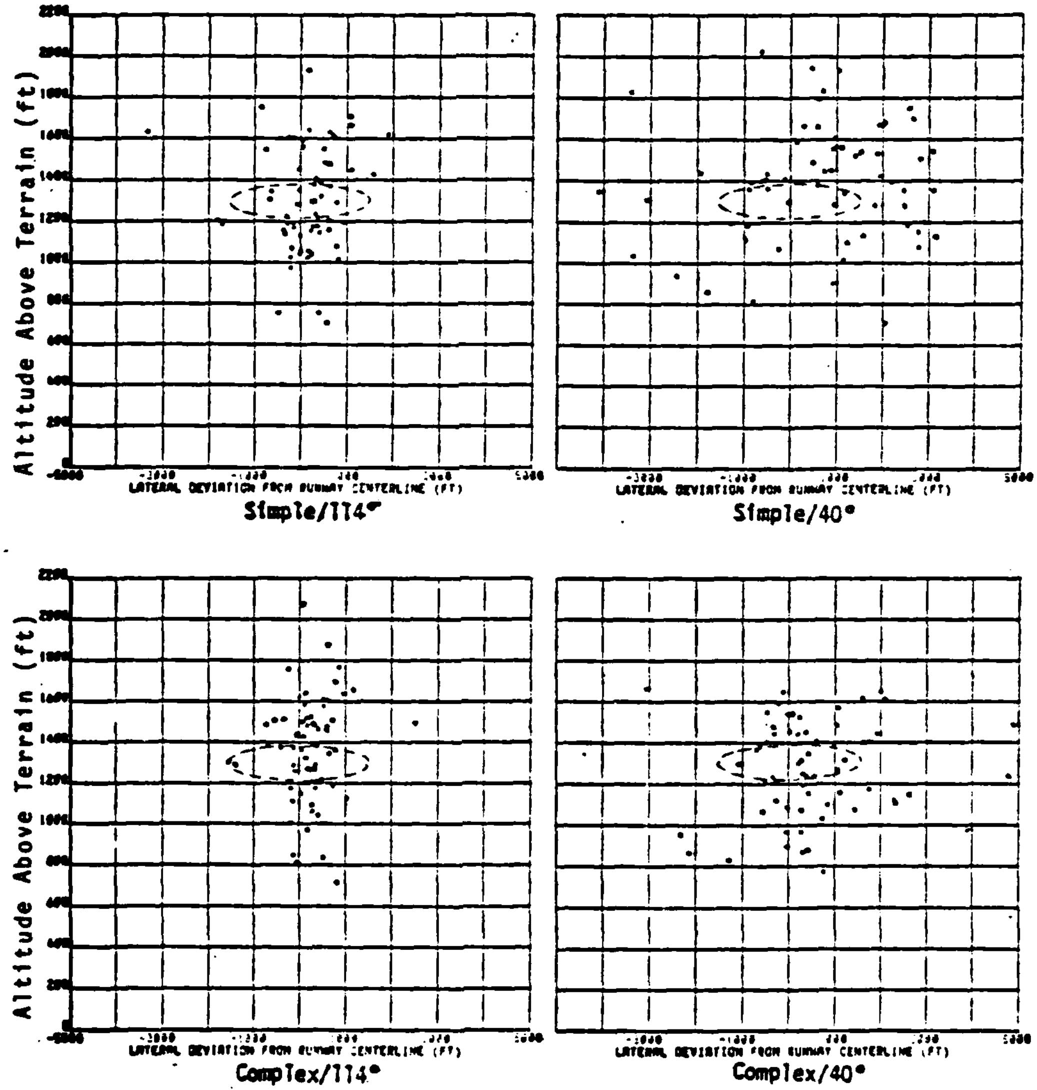

Figure 3. Spatial dispersion (altitude by lateral deviation) of all pilots on the four treatment conditions sampled at the end of the 90° turn. Ellipses = Azimuth and elevation limits (± 2 dots) of the instrument landing system (ILS) on the acceptance area for "precision" approaches.

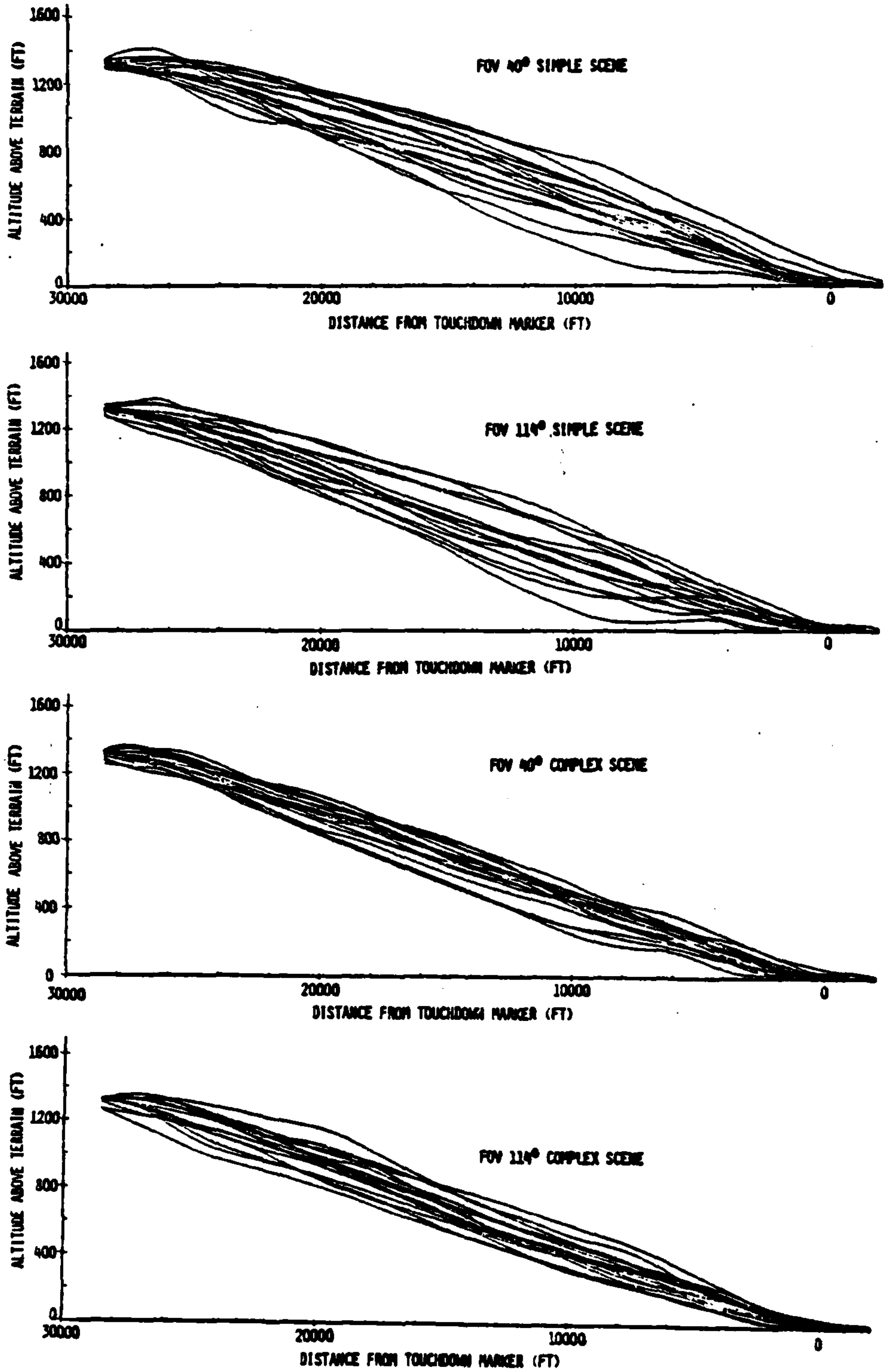

Figure 4. Flight paths of the 16 pilots on trial 4 of Experiment #2 for each complexity and field of view.

Experiment #3

The third experiment involved the use of color in the visual simulation as a test of potential interaction with a visual phenomenon called chromostereopsis. Some of us see colors at different depths as a function of their dominant wavelengths. The "blue" end of the visible spectrum may be seen as closer than the "red" end. Some may have the opposite perception of "red nearer" and yet others may have no differential depth perception associated with hue.

This experiment was similar to the second in that the flight was a straight-in approach and toucndown. There was, however, only one visual field size - - 114°. This dimension was replaced by blue vs. red surrounds for the blue/black runway, its relation to chromostereopsis being the primary concern of this experiment.

The buff color or "sandy soil" surround for the runway in the simple scene of the first and second experiments was replaced with red or blue surrounds to test the effects that this hue difference might have on observers with "red-advancing" vs. "blue-advancing" chromostereopsis.

The runway surround color did have a significant effect on approach and landing performance. For the approach path the runway surround color and chromostereopsis grouping interacted as if perception of altitude was the influencing factor. The blue advancing group remained higher longer against the blue surround and the red advancing group remained higher longer against the red surround. These performances are consistent with the pilots perceiving that they were lower when the surround color appears nearer and they responded by descending slower or delaying the descent.

The influence of surround color and its interaction with chromostereopsis is most apparent in the data on touchdown, the red advancing group landing longer with the red surround than the blue advancing group.

The neutral chromostereopsis group tended to land closer to the touchdown point than either red-advancing or blue-advancing groups. In the case of the blue runway surround, the difference between advancing red and blue advancing groups was relatively small, both show an overshoot while the neutral group again came closer to the intended touchdown distance. A tentative hypothesis to account for the observed differences in touchdown distance would be that when the surround color contrasts strongly with the runway color (red vs. blue/black), the tendency to overshoot is stronger if the surround corresponds to the "nearer" hue in the observer's chromostereopsis. Touchdown means and standard deviations for touchdown distances by the three chromostereopsis groups is shown in Figure 5.

IMPLICATIONS OF EXPERIMENTAL RESULTS FOR TRAINING OPERATIONS AND FOR FUTURE INVESTIGATIONS

The size of the field of view was significant in its effects on approacn and landing performance both in the descending turn and on the

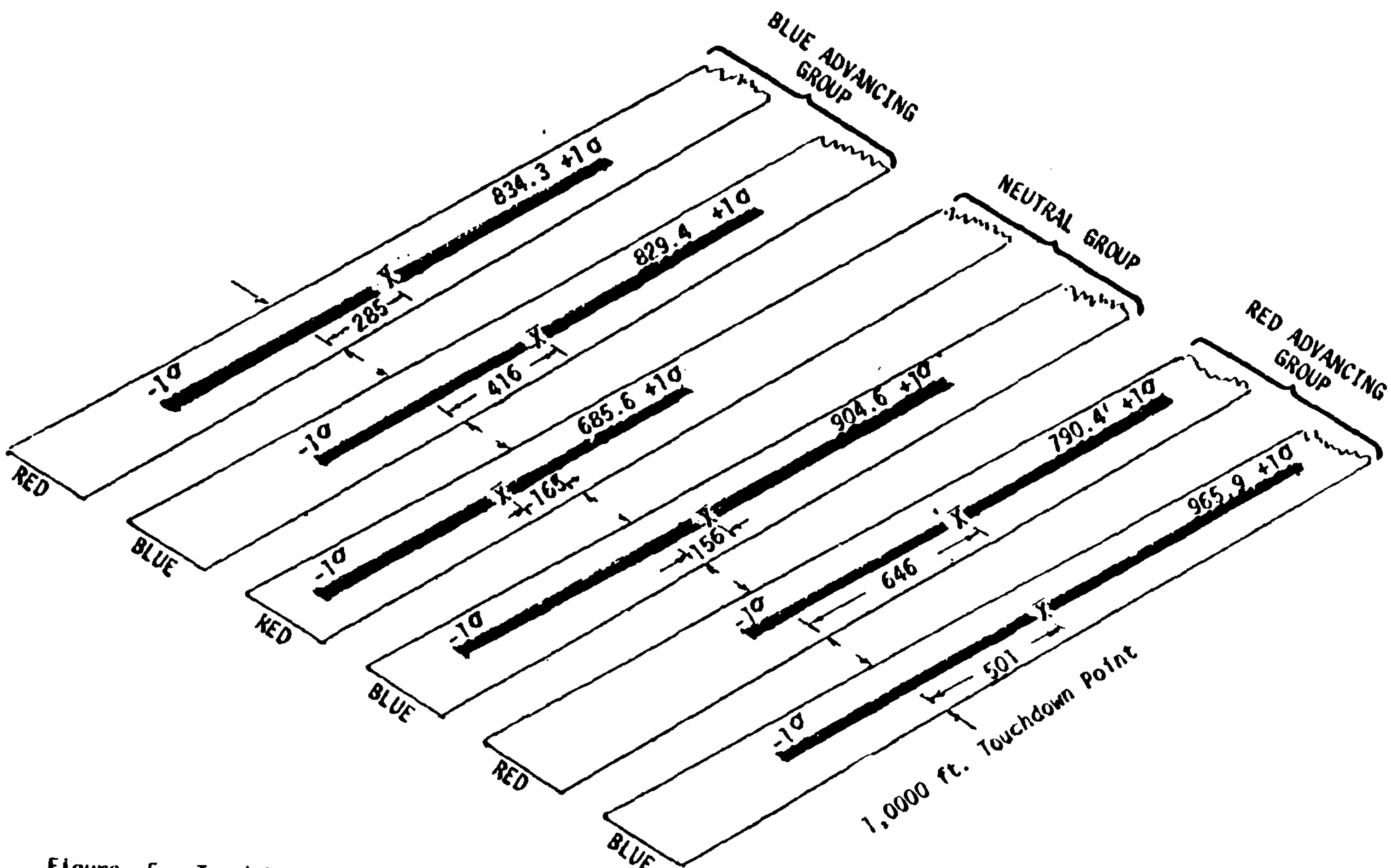

Figure 5. Touchdown point as influenced by chromostereopsis grouping and color of runway surround.

straight-in approach, although for obvious reasons it was more critical for the turn. Therefore, training with a visual simulation which is unrealistically small may result in the inculcation of poor flying practices in the student pilot, e.g., turns that are tighter than desired. The additional cost for larger visual simulators may thus prove necessary for the achievement of training goals.

Scene complexity also plays a significant role in the quality of flight performance as greater detail in the scene appears to aid the pilot in achieving the line-up with the runway centerline. If these cues in the more complex scene constitute an important aid to training and consequently shorten training time, the increased computer capacity needed to provide greater detail may be worth the cost.

The fact that a pilot's depth perception can be significantly affected by the color used in visual simulation and that this tendency appears to vary among individual pilots suggests that attention be paid to color realism in the simulation and to its careful control and recalibration on a periodic basis.

The study results reported here are rather obviously not exhaustive, not only because of the limited number of values (two for each of the major variables) but also because no test had been made of the meaning they may have for the operational training situation in terms of the degree of transfer to be expected. Are the observed effects, though statistically significant, relatively unimportant in training operations? This is an important area of investigation which could be undertaken in a systematic manipulation of the above variables within the training simulator context. Student pilots could be trained with one set of conditions (e.g., simple scene or small field of view) and tested on the more realistic simulation.

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PREFACE

This report was prepared by the Crew Systems Technology and Simulation organization of Data Processing Technology, Boeing Aerospace Company, Seattle, WA. The work was done under USAF contract F49620-79-C-0030 for the Life Sciences Directorate of the Air Force Office of Scientific Research (AFSC) Bolling Air Force Base, D. C. The authors are most appreciative of Maj. Jack A. Thorpe's and Dr. Genevieve Haddad's advice as monitors of this contract.

The authors are indebted to the Flight Crew Training Directorate of the Boeing Commercial Airplane Company for the use of the 747 simulator and the directorate's capabilities. Special thanks are due to Don Baldschun for the development of the special data bases and Roger Stelmack for his assistance in developing the software to make the recording systems amenable to our research. We are also indebted to Capt. Harley Beard and Capt. Jim Adams who served as instructor pilots.

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Capt. Bill Edwards
Maj. Frank Frenette
Lt. Col. Jennings Furlough
Maj. Jonathan Hicks
Capt. Stephen Hoyle
Capt. Marc Isabelle
Capt. John Kent
Capt. George Lanphear
Maj. Terrence McLean
Capt. Jerry Newquist
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1st. Lt. Timothy Thomas
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INTRODUCTION

The United States Air Force's major goal is to maintain a combat-ready air arm for the defense of this country. Today this is difficult to achieve as very high performance airplanes are expensive, and the cost of fuel that must be consumed in maintaining skill through practice has increased many fold. In addition, it is very difficult to measure the proficiency of combat pilots. To do so requires the constructing of complex war games, as at instrumented test sites where the offensive and defensive weapons of an enemy must be simulated. The methods of measuring performance in such complex tasks as low-level (under radar) penetrations against "lethal" weapons requires expensive and complex electronic readouts. Such "war games" evaluation requires large contingents of personnel and equipment moved to a specific location, months of planning and detailed data recording followed by analysis and interpretation.

In the future combat readiness must depend on flight crew training with simulators to train a sufficient number of pilots and maintain a high degree of readiness. With simulators this may be done without consuming large amounts of fuel and speeding up the aging of very expensive aircraft. On the surface this sounds like an easy solution. It becomes expensive when one sees the complexity of the simulators and their visual systems. The real danger does not lie in costs however, but in the possibility that the validity of the training and its transfer to flight performance may not reach the assumed levels. The Viet Nam situation pointed out the high probability of loss of a pilot in the first ten hours of his combat flying. If we must wait until combat trials exist to test the degree of transfer of our simulator training, then we are flirting with disaster.

The solution is to conduct the proper amount of research to economically establish: (a) the reliability, validity and transfer of training from simulation to operational combat flying; (b) the essential content of the external visual scenes required for such training; (c) the quantity and type of motion cues that are essential for each combat task; (d) the cue coordination that facilitates simulator training and transfer of such training and (e) what quantity of initial recurrent and specific aircraft training is necessary to maintain combat readiness.

Considering research item (b) above, it is most disconcerting to realize that scientifically we do not know what information to put in the visual scene to assure that it provides the pilot with the information he will need to learn to fly or to save his life in combat. The absence of such information is understandable. The existence of visual systems with day and night capability, flexible data bases, and visual lags of less than 100 milliseconds does not span more than five years. Only one existed in '74, two in '76 and three in '78 and a rapidly expanding number have been developed in the past two years. However most or all of these have had most of their time committed to training with a small fraction of the available time designated for research.

Without complex simulators and real time dynamic visual systems. relevant research as to the requirements of the visual scene, the display system, its interactive role with the motion platform and the specific operational task will not be completely satisfactory. The limitations of generalizing from static displays to dynamic displays is questioned by the work of Flock (1962), Braunstein, (1968) and Braunstein and Payne (1969). Their results suggest that motion overrides static indicators of slant and in many cases may dominate the slant. A pilot's judgment of the slant of the surface beneath his aircraft in nap-of-the-earth flight may be derived more from the visual streaming of passing objects than any physical description of that object (Reed, 1979)

Simulator designers, operational commands and training syllabus developers all need to know the requirements for visual systems for specific Air Force tasks. Certainly the task of nap-of-the-earth flying at high speed has a different scene complexity requirement than does air-to-air combat. The question is -- how different? Theoretically the air-to-air task will require higher system resolution while both tasks may have a common requirement that the change of object size with closing distance be accurate and continuous.

Quantitative and valid data upon which to base new simulator designs and the upgrading of existing designs is needed now. However we do not now have nor can we see in the immediate future all the necessary controlled investigations of what is needed to meet this immediate demand for simulator visual system designs. In the absence of having such data we will follow the same path that was followed in the development, acceptance and requirements for motion platforms. The history of the development of motion platforms in flight crew training simulators is that they were conceived as a "possibility" Then, without the basic research to establish the design criteria, or the need, they were developed by the aerospace industry to a high degree of sophistication. Accepted by the Federal Aviation Agency (FAA) as ground rules for accreditation, they are now being questioned as to their validity. A parallel development is that industrial capability has made the computer capable of providing a flexible, relatively authentic, highly mobile external visual scene. The competition to produce these for use by civil and military organizations provides a motivation to develop more and more apparent realism. This may by chance eventually lead to providing all the things that are useful for transfer of training. However, the cost-effective way would be to establish what the essential elements are and expend only the money necessary to assemble the effective and essential aspects for combat and every day flight operations.

THE PROBLEM

These experimental investigations were designed to provide data on three fundamental aspects of the visual scenes and display designs for flight simulators. The need for wide fields of view in military simulators, the degree of complexity of the visual scene and the effect of CGI scene color on pilot performance were these aspects.

Field of View

Field of view is a very important variable in fighter aircraft design. Vigilance in search of all areas around the aircraft for possible enemy attack leads to pilot survival. LeMaster and Longridge (1978), in an investigation of the importance of field of view to air-to-surface bombing showed that the larger fields of view were associated with greater accuracy of bombing. Air transport instructor pilots have strongly supported the need for multi-channel (larger field of view) visual systems for training pilots to make circling approaches for landing However the same instructors believe that a single channel forward display is adequate to train pilots to make straight in approaches to the runway. From visual considerations the field of view provided by multiple windows in a simulator is used in two ways by pilots. The first is where the pilot scans the field by looking in various directions for a landmark or target; that is, using side windows in a pattern detection mode. The second aspect is in landing the aircraft where the center of attention and vision is on the pattern of the runway ahead. The role of the side windows is to provide peripheral portions of the retina of the eye with the necessary stimulation to perceive orientation and relative motion. These types of information may be perceived through the side window without the scene having sharply defined patterns or being in focus or necessarily being of high contrast. In making straight in approaches, the pilot is not using the side window to discriminate small details, but, while looking ahead, is in effect using the contribution of the moving, out-of-focus, far peripheral stimulation to provide orientation about aircraft attitude and to discriminate speed.

Experiment 1, to be described in greater detail later, was designed to use a descending left turn of 90° to study the importance of the field of view when pilots used the side windows in a pattern mode. Experiment 2 was designed to study the importance of the side windows when the stimuli seen through these windows is peripheral in the visual field.

Color in CGI Systems

A recent workshop on the importance of color in visual systems for flight simulators (First Interservice/Industrial Training Equipment Conference, Orlando, Florida, 1979) concluded that there were no critical quantitative data to support or deny the importance of color in visual systems for flight training. Furthermore the workshop concluded that, in the absence of such data, the additional expense of such systems did not appear to be warranted.

Theoretically two characteristics of the human visual system may contribute to different spatial localizations of colors when their dominant wavelengths differ. These are the longitudinal and the transverse chromatic aberrations as described by Le Grand (1967). The magnitude of these aberrations differ from individual to individual. Changes in pupil size, axial lengths of the eye, and stereoscopic skill are all likely to differ among individuals and influence the perception of spatial localization of colors. A stereoscopic spatial localization of colored objects that is due only to hue is called chromostereopsis by Vos (1960).

Experiment 3 was designed to measure the different amounts of chromostereopsis to be found among a small sample of pilots and to stratify these pilots into three groups based upon the quantitative amounts of their personal stereopsis. Then they were asked to fly a simulator toward runways of a common hue, but of surrounds that differed in hue. This experiment was deemed to be exploratory to find out whether these individual differences in the visual systems of pilots would influence their performance in a simulator with a CGI system that had the possibility of chromatic differences that could be used to differentiate objects, fields, and other things within the visual scene.

Complexity in the Scene

Complexity in computer generated image visual systems is generally reported as the total number of lines or polygons that may be displayed across all available channels. Computer size, number of crossings of a raster line, number of models, limits of throughput time, and total system cost impose practical limits to scene complexity.

The other side of this question is not duplication of the real world scene, but the critical information content in the visual scene for the pilot to accomplish his assigned task. Low-level, terrain-following flight may be dependent upon the number of units per area to give an adequate streaming effect in the visual periphery. Air-to-ground reconnaissance, on the other hand, may be dependent upon the number of edges necessary to draw the details of a target and to properly illustrate the surround from which it must be visually differentiated. A large field of view may have little practical importance if the scene displayed has few or no differentiating patterns. The peripheral visual area may need to have different size and contrast in objects so that they are adequate stimuli for orientation cues. Such size and contrasts may be very different than the requirements of the fovea for patterm recognition.

Two levels of this variable were used in all three experiments conducted under this contract. The simple scene was a blue/black runway as the single object seen in a completely homogeneous field. The color of that field was a sandy soil for experiments 1 and 2, and red or blue for experiment 3. The complex scene was a multi-colored representation of the Moses Lake area in the state of Washington in experiments 1 and 2 and was colored red or blue in experiment 3. The degree of complexity was less than 333 edges in any one channel or a limit of less than 1000 in all three channels. This complex scene, with a normally marked runway has been used to train over 1000 pilots to transition to four models of air transports.

METHOD

EQUIPMENT

General Description of 747 Simulator

The three experimental psychophysical investigations of pilot performance as a function of field of view, color and complexity of the computer generated images were completed using the most modern 747 simulator. This is the new Redifon 747 simulator with a General Electric Compuscene visual simulation system certified for flight crew training in April 1979. It is located at the Boeing Flight Training facility. The general floor plan and identification of major components are illustrated in the three-dimensional drawing of Figure 1. The simulator is configured as a current production 747-200 with Pratt and Whitney JT9D-7F engines.

The simulator instructors' station with side-by-side seating for a pilot instructor and an engineering instructor is located at the left rear of the simulator compartment and utilizes the Redifon modular advance graphics generation system (MAGGS). The MAGGS is intended to reduce the instructor's workload insofar as possible by automating the lesson plans and allowing the automatic insertion of malfunctions.

In the experimental situation two experimenters replaced the instructors and functioned as simulator and recording equipment operators. MAGGS also provides graphic capability for use by the simulator instructors during training. The instructors may call up color plots of radio navigation maps and localizer/glideslope performance indicators which can be displayed simultaneously on two cathode-ray-tube screens. These were used by the experimenter to provide a Ground Control Approach (GCA) type of display of a plan view of azimuth position on either side of the centerline of the runway and, immediately below it, a glideslope deviation display which shows altitude as a function of distance from the touchdown point. These displays were used by the experimenters to monitor the performance of the pilots of experiment 2 for each of the 256 trials, and for each of the 240 trials in experiment 3. Utilizing the same MAGGS capability we were able to remotely record on electromagnetic tape data from the simulator computer. In this experimental investigation 37 parameters were recorded at an average rate of once every 450 milliseconds. Two capabilities were not used, those of plotting in real time or extraction of hard copies.

A General Electric day/night Compuscene visual simulation system is installed on the Redifon 747 flight simulator. Boeing designates this system as the G. E. Compuscene 4000 based on the original G. E. Compuscene 1000 but having a capability in excess of the earlier model and incorporating a number of the state-of-the-art advances. The system presents computer-generated infinity color images with variable visibility and ceiling covering a horizontal field of view (FOV) of 74° (two channels juxtaposed) for each pilot in the forward mode, 114° for the selected pilot in the side mode, or a 40° FOV (single channel mode). The vertical field of view is 30°.

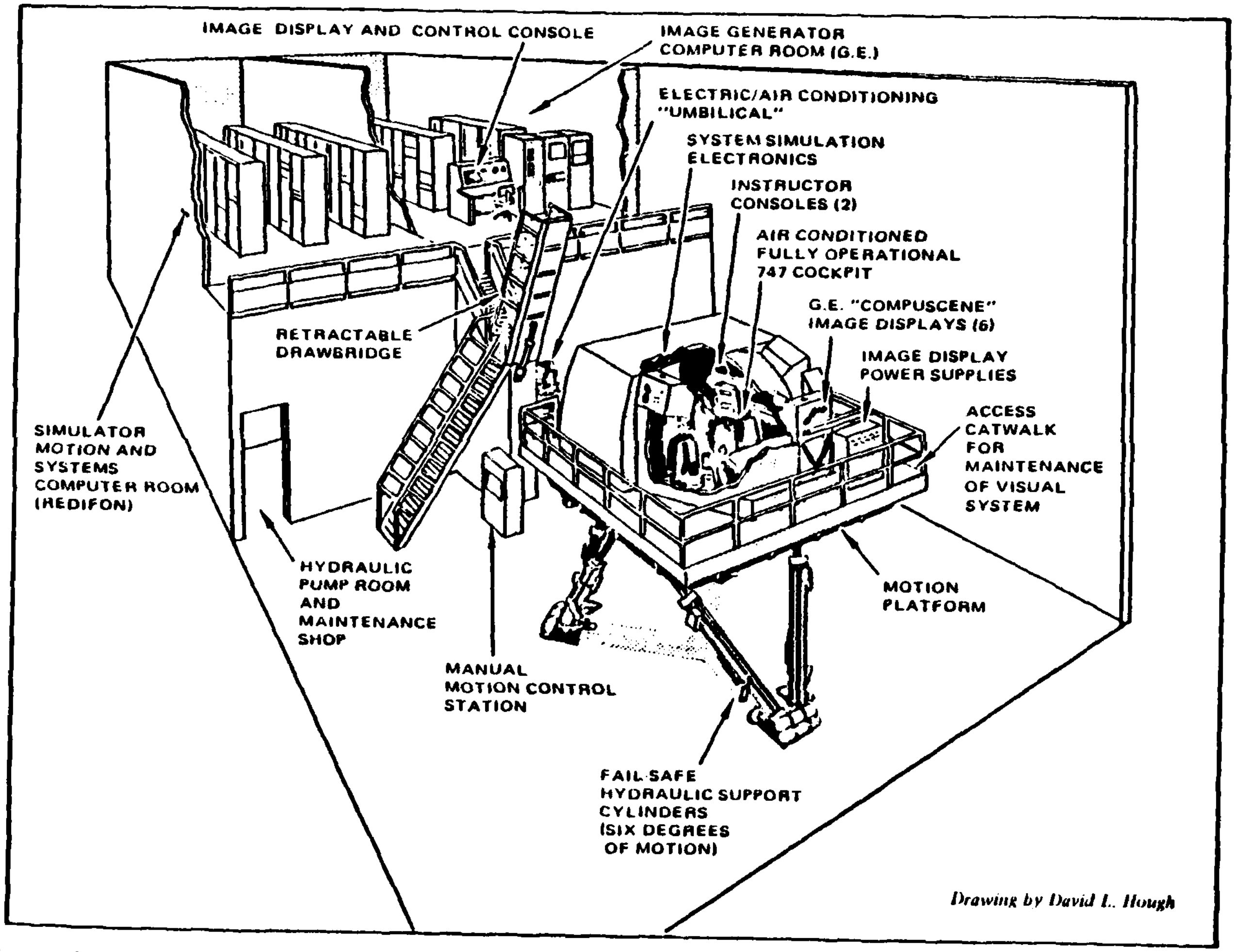


Figure 1. Redifon 747 flight simulator - floor plan and identification of major components.

Each window display can portray in true perspective the runways, the landscape scene and lights falling within its field of view in real time dynamic response to movement of the simulated airplane in 6° of freedom. The system is capable of presenting full day, dusk and night scenes with 4000 potentially visible edges and 2000 lights. The storage environment capability is 8000 edges. Enhancement includes such options as full three-dimensional occulting, scud, runway face blending, moving models (airplanes or trucks moving onto the runway), and an off-line data base generation system.

The motion platform supporting the 747 simulator cab is a six post synergistic system based on a Reflectone development of the original Franklin Institute design. It is similar to the Air Force motion base for the E3A simulator at Tinker Air Force Base with a minor structural change in the upper attachments. It is not of the newer hydrostatic design now being offered by Redifon. In all of the experiments to follow motion was used throughout all the experimental runs.

The experimental flight conditions were set up using essentially Flight Crew Training's lesson number 5 through the MAGGS system as follows:

Parameter	Action or Value
Ground proximity warning	Pulled
Altitude select (a warning)	5,000 ft. AGL
Flaps	30°
Auto/manual select	Manual
Fuel quantity	Frozen
Gross weight	263,000 kilograms (V Ref = 140K)
Center of Gravity	16%

The malfunction (MAL) index was used to execute certain aids:

VHF/NAV Receiver	Failed
ADF Receivers 1 and 2	Failed
Outer and middle marker lights	Failed
Decision height light	Failed

These "failed" aids removed altitude and position information normally available from the instrument landing system and radio beacons. Paper occluders were also introduced to conceal barometric and radar altimetry,

vertical speed indication and a view of the co-pilot's instruments from the captain's left seat. These experimental controls required the Air Force pilot to obtain distance and height information from the visual scene. Therefore all the approaches made in the three experiments were "non-precision approaches" (i.e. without special radio aids) and were dependent upon external visual information.

Special Data Bases

Special data bases were used in this study for the Air Force Office of Scientific Research (AFOSR). These were all modelled on Moses Lake Airport (MWH), also known as Grant County Airport. Moses Lake is in central Washington state, a former Strategic Air Command (SAC) base with a 13,500 ft. by 300 ft. runway. This runway has a 50 ft. cement apron on both sides, a feature not reproduced for this investigation. The 321° heading of the runway was maintained, but the mixture of cement and macadam surface was replaced by a homogeneous blue/black macadam surface devoid of any runway markings. The MWH origin of the glide slope at 1840 ft. from the threshold was also maintained for the computer reference. The glideslope shack to the left of the runway on the approach was a visual reference point in the more complex scenes. All other visual references, such as runway centerline, threshold marks, and 1000 ft. marks were not included in either the simple or the complex scene.

The composition of the "simple scene" was the homogeneous 13,500 ft. long 300 ft. wide, black macadam runway, in a "sandy soil" homogeneous surround. The area that surrounded the runway had no differentiations by lines or objects. It was like the Sierra desert in a light sandstorm. This version of the simple scene was used in experiments 1 and 2. The complex scene has the same runway, set within the Compuscene image of Moses Lake, Washington (MWH), a scene that has been used to train more than 1000 airline pilots. This scene is flat western terrain made up of cultivated fields of different colors and areas, with a river and a series of small lakes. To the left of the runway there is a taxiway and a large hangar and tower.

Since the number of edges was insufficient to reproduce the actual buildings on the right of the runway these were replaced by a series of artificial images to provide visual stimuli to peripheral portions of the visual field. These are a series of interlocking diamonds of sufficient size and contrast to be seen 70° off the visual axis. There are two parallel rows of these on either side of the runway. The inner row is fairly close to the runway, the outer row quite a distance away. They provide a differentiation of the visual peripheral field surrounding the runway.

These simple and complex scenes were also duplicated in slightly different form for experiment 3 which was principally directed at the influence of the peripheral color in pilot performance. The simple scene had the same runway described above, surrounded, in one instance, by a red peripheral field and in the other by a blue peripheral field. The details of selection, matching and assignment will be discussed in more detail in the section devoted to experiment 3.

In the complex scene the same Moses Lake data base from the Compuscene was used, but colors assigned to the different physical objects in the peripheral field were of the same hue and differentiated by changing saturation. By adding white to the basic hue the taxiway was made perceptually a pattern that could be differentiated from the ground plane.

PROCEDURE

Dependent Measures of Pilot Performance

Good quantitative indices of pilot performance in the approach and landing segment of flight in commercial jetliners are not easily found. The reason for this may be that acceptable performance is not too difficult for pilots to achieve in the test situation, thus making it extremely difficult to find meaningful variation among pilots or between experimental conditions. Normally, deviations from glide slope (up or down) and from localizer (right or left) are visible as part of the flight direction display, and the pilot can refer to barometric and radar altimeters as well as to airspeed and vertical speed indicators. In the present test situation these indicators of aircraft position and motion were not available to the pilot (except for airspeed), though they were present in the right-hand instructor pilot's display. It was desirable that the performance data reflect the influence of the independent variables rather than the pilot's ability to ignore the variations when instrument indications were available.

For the most part in these studies, the resulting effects of pilot actions were used as the dependent performance measures. That is, flight parameters such as aircraft attitude, flight path deviations, velocities, and touchdown descriptors were used as utilitarian indicators of the effect of the independent variables upon pilot performance. While these variables were relatively easy to monitor and record, they do not provide the overall appraisal of pilot performance that might be available from an instructor pilot/evaluator. However, it was felt that the objectivity and reliability of the simulator variables outweighed the limitations of interpreting several discrete measures of performance effects.

Data Recording Procedure

The data recording capability of the SEL 32/55 computer supporting the new Boeing 747 simulator was structured to provide the recording onto 9-track magnetic tape of up to 100 variables. Selection of a "snapshot" interval of 450 msec resulted in a data recording frame rate of 2.22 frames/second. The simulator data base provided a total of over 1000 variables from which to select 100 or less as those potentially important to these studies. An initial wish-list of primary dependent variables had been developed and this was supplemented by examination of the simulator data shopping-lists. A total of 37 variables were selected for recording, along with several discrete "flags" such as altitude, position freeze and trial number. The 37 dependent variables are described in Table 1. Of these, the first 20 were subsequently selected

Table 1. Recorded flight performance variables.

#	Acronym	Definition
1.	H	Altitude (in feet) of aircraft center of gravity above terrain.
2.	GSPE	Vertical deviation (in feet) from the electronic glide-slope of 2.5° which intersects the runway at 1840 feet from runway threshold.
3.	GSCAL	A calculated vertical deviation from a glide slope of 2.7° which contains the vector running from the initial aircraft position to the intersection with the runway at the visual approach touchdown point 1000 feet from threshold (in feet).
4.	LONG	Ground track distance along the extension of the runway centerline measured from the electronic glide slope intersect point at 1840 feet from threshold (in feet).
5.	LONGAV	A calculated value of LONG measured from the visual touchdown point at 1000 feet from threshold (in feet).
6.	LATD	Lateral displacement from the runway centerline or its extension (in feet).
7.	ROC	Rate of climb (in feet/second).
8.	VTRU	True airspeed in feet/second (there was no wind velocity vector).
9.	THTA	Aircraft pitch angle (in degrees).
10.	THE+	Pitch angle change rate (in degrees/second).
11.	AOA	Aircraft body angle of attack (in degrees).
12.	ROLA	Aircraft roll angle (in degrees).
13.	PHI+	Roll angle rate (in degrees/second).
14.	PSIA	Aircraft heading measured from runway vector of zero degrees (in degrees).
15.	PSI+	Heading rate (in degrees/second).
16.	PL#2	Power lever angle on engine #2 (in degrees).
17.	PL#3	Power lever angle on engine #3 (in degrees).

Table 1 (cont.)

#	Acronym	Definition
18.	TGR	Total gear reaction: sum of individual gear reactions (in pounds).
19.	PWGC	Port wing gear compression (in feet).
20.	SWGC	Starboard wing gear compression (in feet).
21.	TRL1	Throttle setting on engine #1 (in RPM).
22.	TRL2	Throttle setting on engine #2 (in RPM).
23.	TRL3	Throttle setting on engine #3 (in RPM).
24.	TRL4	Throttle setting on engine #4 (in RPM).
25.	BETA	Aircraft sideslip angle (in degrees).
26.	IAS	Indicated air speed (in knots).
27.	CADC	True air speed (in knots).
28.	HTER	Altitude above sea level of runway and approach terrain (in feet).
29.	RALT	Aircraft radar altitude (in feet).
30.	MSL	Aircraft altitude above sea level (in feet).
31.	TD	Aircraft on ground flag tripped by weight or compression on gear.
32.	PL#1	Power lever angle on engine #1 (in degrees).
33.	PL#4	Power lever angle on engine #4 (in degrees).
34.	ZAGL	Altitude above terrain of pilot's eye reference point (in feet).
35.	GSLD	Aircraft positional latitude (in degrees).
36.	ALAT	Aircraft positional latitude (in degrees).
37.	ALON	Aircraft positional longitude (in degrees).

to form a basic data set from which variables, or combinations of variables could be accessed for statistical analysis. Thoughtful selection of those variables to be analyzed was necessary since, counting added identifiers, there were over 7 million data items in the original recorded data base.

Statistical Analysis Procedure

The data recorded on magnetic tape by the SEL 32/55 computer required some interface development before they could be accessed for analysis. This was because there were a variety of data formats and types used in the original recording of the variables. A software program was developed to interpret the data "header" and reconfigure the data into floating point decimal format with variable and variable-level descriptors. This procedure was set up on a VAX-11 computer with interactive terminals, co-located and tied into a General Graphics Package supervised by a PDP-11 computer system.

The factorial design of the experiments was most amenable to analysis of variance statistical treatment. Each of the designs is a complete factorial with repeated measures (each pilot/subject had each experimental condition). The pilots flew four consecutive approaches to each combination of independent variables. In most instances, there was a significant "learning effect" over these four approaches and therefore they were treated as a fixed effect ("Trials") rather than as replications. All effects were treated as fixed except "Pilots," and the F-ratio tests were made between the treatment and pilot x treatment interaction mean squares. In some instances it was hypothesized that the variance rather than the mean of the dependent measure would be more indicative of performance under the experimental conditions. In these cases, analysis of variance was run on the natural log transformation of the variances across the four trials of each combination of the independent variables.

SELECTION OF PILOTS

Experiment number 3 called for the stratification of pilots into three categories by their individual chromostereopsis thresholds, i.e. (a) those who saw blue as advancing (or nearer) than red, (b) those who had very little chromostereopsis and could be considered as neutral, and (c) those who saw red (long wavelength colors) in front of short wavelength colors, a group we call "red advancing." Arrangements were made with McChord Air Force Base in Washington state through the auspices of the Air Force Office of Scientific Research for us to have the opportunity to test a group of pilots from the Military Air Transport Command. The survey of special visual skills was done at McChord AFB using their facilities with visual test equipment brought from Boeing in Seattle.

Initial selection was on the basis of chromostereopsis using the Alternating Ramp Test developed for the Air Force Aerospace Medical Research Laboratory in a previous investigation (Anderson & Kraft, 1976). This

test uses nine rows of horizontally arranged discs which follow a linear ramp function from one end of the row to the other with the condition that the direction of the ramps is always opposite in adjacent rows, and the colors (red versus blue rows) were also alternated. The disc sizes are varied and the task for the observer is to locate the single vertically adjacent pair which appears to be the same distance away from the observer as viewed through a Wottring Troposcope.

For an observer with red advancing chromostereopsis (that is, seeing red closer than blue) the decision point should shift toward the end of the row where the blue discs are higher than red discs. A shift from one column to the adjacent one was equal to about 24 arc seconds of disparity for the series used in this survey. Each of the Air Force pilots was asked to make judgments on three pairs of stereograms, or 27 different matches of alternating pairs of rows. The responses could then be converted into a threshold for chromostereopsis reported in arc seconds. The chromostereopsis measurements for the 25 pilots used in this survey will be found in Appendix A.

In addition to the chromostereopsis test, a specialized test on depth perception was also presented in the stereoscope. This Critical Limen Stereo Test was given to the pilots in both black and white and in color.

Based on these tests, a selection was made of 15 individuals; five represented the blue advancing, five represented the neutral and a third group of five represented the red advancing. The selection gave us a good match in terms of mean chromostereopsis. As shown in Table 2, the blue advancing group represented 48.2 arc seconds of chromostereopsis. The neutral group had a mean of 1.08 arc seconds and a very slight magnitude of red advancing. The red advancing group also had a 48.1 arc second average chromostereopsis. This matching made an equal average displacement on either side of no chromostereopsis for the red and blue advancing group.

The dispersion of scores around the mean were not too different for the three groups as shown by the standard deviation. The match was also fairly good in terms of the age of the pilots, the mean age being about equal for each of the three groups. However the number of hours of experience was not as good a match. The blue advancing group had much more experience than the red advancing group.

The stereoscopic skill of the groups were in the order of the neutral being best at 7 arc seconds, the red advancing at 12.2 and the blue advancing at 33.8. The color discriminations were fairly similar as far as means were concerned. There was more dispersion due to one individual in the red advancing group. However, the skill in color discrimination was all in the upper 30 percent of an unselected population.

The selected pilots traveled to Boeing to fly the simulator. We had provided for four hours of additional visual testing as each pilot had eight hours in Seattle, four of which were planned for the simulated flights. The visual skills were extended to include visual acuity at

Table 2. Comparative age, experience and visual skills of three chromo-stereopsis groupings of pilots.

	Age		Flight Hours		Chromo-stereopsis		Acuity Far	
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
Blue Adv.	34.8	7.9	3432	3336	48.2B	9.0	0.58	0.17
Neutral	32.9	7.4	2100	2484	1.08R	8.3	0.50	0.00
Red Adv.	32.6	6.5	1730	1643	48.1R	9.9	0.67	0.22
	(years)		(hours)		(arc seconds)		(arc minutes)	

	Stereo Skill: Achromatic		Stereo Skill: Chromatic		Color Discrimination	
	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
Blue Adv.	33.8	20.7	37.4	22.0	26.8*	10.5
Neutral	7.0	2.2	-	-	33.6*	5.4
Red Adv.	12.2	9.5	-	-	26.4*	32.3
	(arc seconds)		(arc seconds)		(total error score F.100H)	

* Upper 30% of unselected population.

far (20 feet) for both the right and left eye, a test of both eyes at near (16") visual acuity, and lateral phoria at far. These pilots had exceptional skill in terms of visual acuity. All but one could exceed the clinical norm of 1 arc minute, discriminating 0.5 arc minutes. Also the lateral phoria was exceptional as nobody had a divergence or convergence greater than 1 prism diopter.

Two tests were planned for the second experimental session that for technical reasons could not be completed. The first was to measure the resting state of cyclophoria, or the wheel-like rotation of the eye, when the fixation is at infinity (> 20') and at near point (16"). However in transporting the powered Troposcope the precise calibration of the lamp houses was destroyed. Recalibration could not be accomplished in time to complete the testing of all pilots. The second test, a version of the duochrome test used in refractions was not possible because the color temperature of the sources had changed at an unknown time during the administration of this test.

Two of the 16 pilots that participated in the first and second experiments did not participate in experiment 3. The demographic information for those surveyed and participating in the 747 simulator experiments are summarized in Table 3 below.

Table 3 . Summary of demographic information on pilots

Topic	Survey		Experiments 1 and 2		Experiment 3	
	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ
Age	33.2	(5.99)	33.9	(6.86)	33.43	(7.3)
Flight hours	2637.9	(2216.8)	2400.6	(2509.0)	2420.7	(1719.6)
Rank (Range)	1st L to Lt.Col.		1st L to Lt.Col.		1st L to Lt.Col.	

The complete table of visual skills, age, experience etc. of the participating MATS pilots will be found in Appendix A.

The attitudes of these pilots were very positive. They were much interested in helping us with the experimentation as well as having the opportunity to fly the new 747 simulator.

EXPERIMENT #1

FIELD OF VIEW AND SCENE COMPLEXITY - 90-DEGREE TURN ONTO FINAL APPROACH

In most visual flight simulators using computer generated imagery (CGI) for external scene production, a major cost variable is the number of display generation channels selected for the simulator. For example, in order to minimize costs, a single display channel design might be selected for a single-seat trainer simulator, providing a forward-only scene of perhaps 30° by 40°. At the other extreme, a horizontal field of view (FOV) approaching 360° and a vertical FOV of 180° or more might be provided for a high performance fighter simulator by juxtaposing numerous displays involving perhaps eight or more display generation channels. Since each additional active display channel usually means a very significant increase in overall simulator costs, one of the most important questions asked early in the simulator design effort is: How many display channels (how large a FOV) does this simulator need? Since the FOV size may also have significant impact on training and simulator utilization, and since these effects are often not well understood or predictable, a definitive answer to this question is usually difficult or highly elusive. This experiment was designed to provide some additional quantitative data in this area.

The Boeing 747 simulator has a total of five display/scene generation channels:

1. Straight ahead view, 20° right and left, with a common display channel data base for displays of captain and first officer;

2. For the captain, a display juxtaposed to the left of the forward display at an oblique, covering 40° with a 6° overlap of channel;

3. For the first officer, a similar display channel juxtaposed to the right of the first officer's forward display;

4. For the captain, a 40° horizontal display channel centered on a line 92° left of straight ahead (covers 72° to 112° left);

5. For the first officer, a similar display channel to his right side.

The basic configuration for these display channels is given in Figure 2, with the first officer's displays being a mirror image of the captain's. The visual scene data base integration provides three possible alternative combinations of these five display channels, each alternative utilizing three of the display channels:

a. The forward scene for the captain and first officer plus both the forward-oblique channels;

b. The forward scene for the captain and first officer plus the captain's forward-oblique and side window channels;

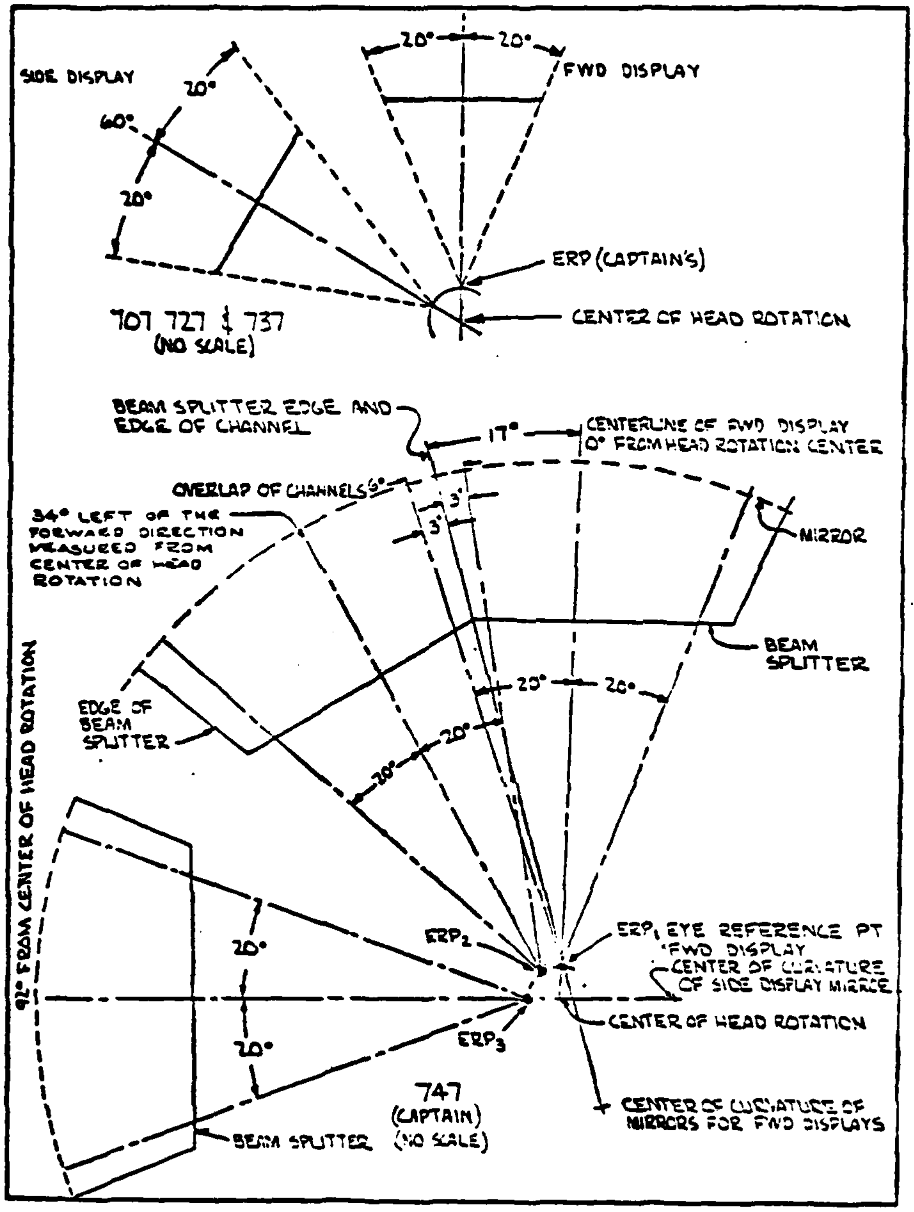


Figure 2. Layout of the three CGI displays for the Captain's position in the 747.

c. Same as in (b) but with first officer's forward-oblique and side window display channels.

METHOD - EXPERIMENT #1

The first experiment was designed to investigate the contribution of the side window scene in making a 90° turn onto final approach with both simple and complex scenes. The side window variable had two levels, available and not available, and the scene complexity variable also had two levels, simple and complex. Each combination of these variables was run for four trials, i.e., each of 16 pilots made four approaches under each of four combinations of the other conditions. The experimental design is shown in the upper left-hand portion of Figure 3. The details of the make up of the two levels of scene complexity have been described earlier. Also covered in the general methodology section were descriptions of the Boeing 747 simulator and the pilots that served as experimental subjects since these aspects applied, in the most part, to all three experiments.

Since the pilot-subjects flew all of the approaches from the captain's seat and considering the task for this experiment, the second and third of the three alternative display channel combinations described earlier were selected to provide the two levels of FOV. Thus the pilots either had only the forward 40° scene (first officer's side windows were active but were a uniform blue during the 90° turn segment) or he had the forward scene plus the left forward-oblique and left side windows available. The total FOVs on the captain's side were therefore 40° and 114° respectively, with an 18° gap between the forward-oblique and side windows.

The task in this experiment was to fly a 2-mile 90° descending turn onto final approach under the various conditions. For all approaches, altitude and glideslope indicators were disabled although heading information was always available. In addition, the pilots were given their initial altitude and location and the desired altitude at the end of the 90° turn (the turning descent was designed to be on a 2.5° glideslope). They were also asked to attempt to fly the turn so as to be lined up on the runway centerline (localizer) at the end of the turn. The ground track of the design flight path is given in Figure 3. The initial position of the simulator was at 6.4 nautical miles out from the visual touchdown point (1000 feet down runway from threshold), measured along the extension of the runway centerline, and 2.45 NM offset to the left of this extension. This provided a short straight lead-in to the 2 NM turn. Data recording was terminated soon after the pilot passed the 3.4 NM out point and the simulator was reset at 4.56 NM out for a straight in approach under conditions of experiment #2. The approaches alternated thus until all of the runs for experiments #1 and #2 were completed - then the approaches for experiment #3 were flown.

As indicated earlier, analysis of variance procedures were used to examine the effects of the independent variables of availability/non-availability of the side windows and of the simple/complex scenes. Since the analysis of variance technique normally utilizes single ob-

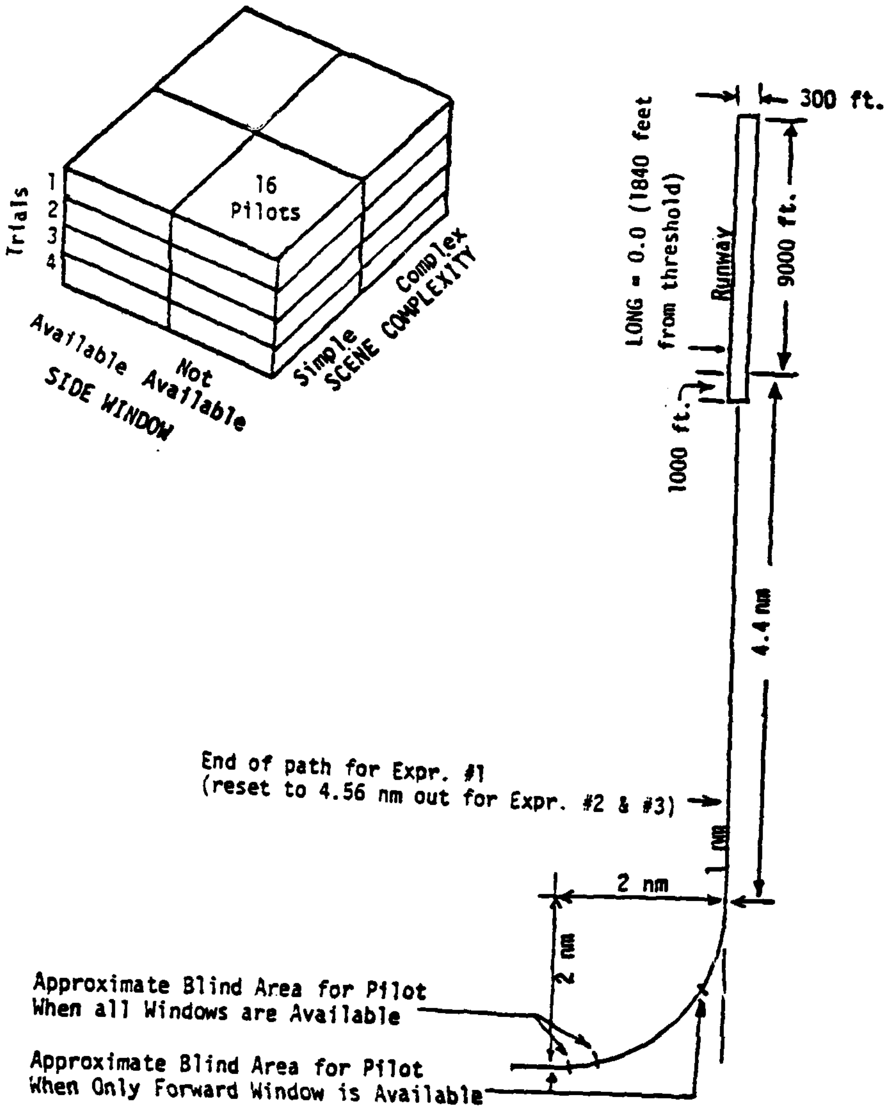


Figure 3. Diagram of experimental design and flight paths for simulator experiments #1 and #2.

servations, the data sets appropriate to such analysis were developed by taking "snapshots" of the data at various points or locations in the 90° turning approach. Three such points were selected for examination of performance in Experiment #1:

(a) at one nautical mile into the flight, defined as the point at which the lateral offset from centerline (LATD) equalled 1.45 NM (8850 feet);

(b) at the point on the theoretical 90°, 2 mile turn that the pilots without side windows available would acquire the runway in the forward display, defined at LONG = 32,100 feet or 5.14 NM out from visual TD mark;

(c) at the end of the theoretical turn, defined at LONG = 27,646 feet, or 4.4 NM out from visual TD point.

It was hypothesized that in the initial segment of the flight leading up to point (a), during which the runway would be visible only in the conditions with the side windows available, that an initial trend in the effect of side window availability might be seen. Shortly thereafter there is a short segment in which the runway is not in view (theoretically) for either of the conditions. Then there is another longer segment similar to the first and leading up to point (b), at which the runway would normally become visible for both conditions. At this point, it was hypothesized that maximum error and/or variance would be found in the flight paths of the pilots for which the runway had not been available. After this point,the pilots have a chance to correct their flight paths according to their perceived relationship to the runway, so it was further hypothesized that any differences between the flights with and without the side windows would be reduced to perhaps no significant difference by the time they reached point (c) described above.

Of the dependent variables available, the initial analysis examined a group of six or so, selected as most to reflect the effects of the independent variables upon the specific task of Experiment #1. The dependent variables used in common for the analyses at the three locations described above included altitude (H), roll angle (ROLA) heading angle (PSIA), and heading rate (PSI+). Those that were examined at two of the three locations included lateral deviation from runway centerline (LATD), vertical velocity (ROC), and roll rate (PHI+). Dependent variables examined at only one of the three locations included distance out from 1840 ft. mark on runway (LONG), true airspeed (VTRU), pitch angle (THTA), and pitch rate (THE+). Thus a total of 11 dependent measures were analyzed at one or more of the three selected locations in the turning approach. More details of which measures were examined at which locations can be found in Table 3 in the next section.

Prior to running the analyses of variance, the data were plotted for each condition to provide a visual representation of performance on the 90° turn. Figure 4 presents the paths flown by the 16 pilots on the second trial for the four conditions of simple scene with side

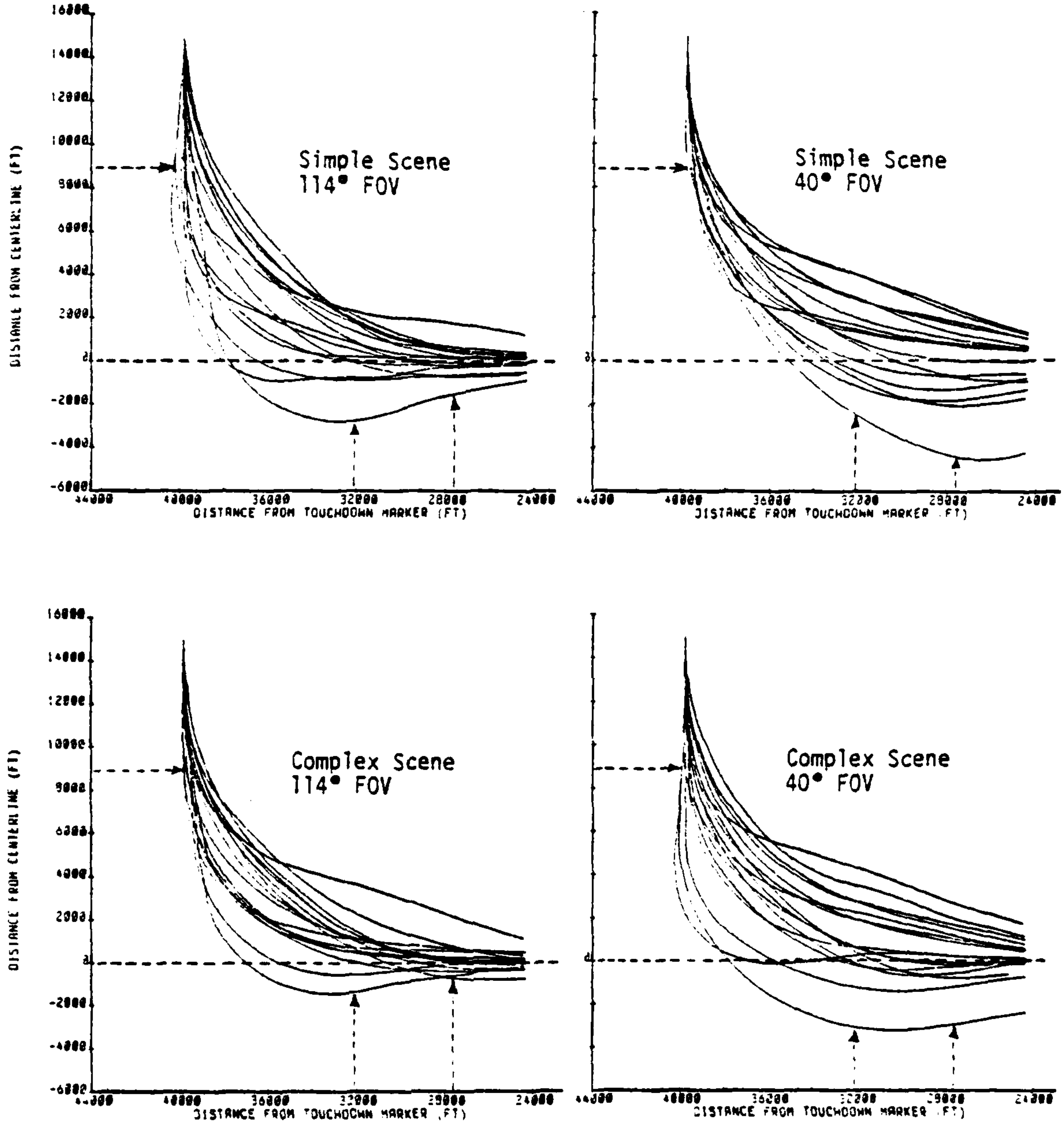


Figure 4. Flight paths flown by 16 pilots in 747 simulator on trial #2 of four conditions of Experiment #1.

windows available (upper left), simple scene with forward display channel only (upper right), complex scene with side windows available (lower left), and complex scene with forward display channel only (lower right). Also shown in each figure are the three locations at which the performance data were analyzed.

RESULTS AND DISCUSSION

The results of the analyses of variance on central tendency were compiled into a table showing which independent variable main effects or interactions were statistically significant at either the $p < .05$ or $p < .01$ levels. This information is presented in Table 4 in a cross-matrix of dependent variables by the locations where data were taken. A cursory examination of this table reveals that the main effects of trials (T), field of view or availability of side windows (F), and scene complexity (S), and the interactions of TxF and FxS were significant at some point for at least one of the dependent variables. The analysis of variance summary tables are all included in Appendix B. In the following sections, tables of means and standard deviations will be used to illustrate various effects.

Effects on Altitude (H)

At 1 nautical mile into the flight, the only significant effect upon altitude was for the main variable of trials. The means shown in Table 5 indicate that successively higher altitudes were being flown up through the third trial, with a leveling off of altitude on the fourth trial. The main effect of trials was not significant for altitude at either of the other two locations analyzed.

Table 5. T-Means

	1694.295	1728.197	1736.600	1736.888
S.D.	159.906	143.427	153.240	150.835

Although neither the main effects of field of view and scene complexity nor their interaction were significant at 1 mile into the flight, a trend was beginning to develop which resulted in significant effects later in the flights. This interaction trend can be seen in the means of Table 6. At the point of runway acquisition and at the end of the turn, this trend becomes a significant effect as shown in Table 7 and 8. Both of these are statistically significant at the $p < .05$ level and show a consistent crossover in the altitude maintained under these conditions. The altitudes flown for two of these conditions, simple scene with only forward display and complex scene with side window, were close to the desired glideslope while the other two were somewhat low. It could be hypothesized that as the display and scene conditions became more limited, the pilots might fly more cautiously and maintain higher altitudes. This view could be supported by the altitudes flown under three of the conditions, but the fourth (complex with side window) should have the lowest altitude accordingly. Thus this consistent and significant interaction remains somewhat of a puzzle.

Table 4 . Significant main effects and interactions for dependent variables submitted to analysis of variance at three locations in 90° turn of Experiment #1.

		DATA SAMPLING POINTS		
ACRONYM	DEFINITION	1 NM INTO FLIGHT AT LATD = 8850 FT	RUNWAY ACQUIRED LONG = 32100 FT	END OF 2 MILE TURN LONG = 27646 FT
H	Altitude of aircraft above terrain (in feet)	T	FxS	FxS
LONG	Longitudinal distance out from 1840 mark (in feet)	F, S	N/A	N/A
LATD	Lateral displacement from runway centerline (in feet)	N/A	T, F	T, F, TxF
ROC	Vertical velocity (in feet/second)		FxS	N.S.
VTRU	True airspeed (in feet/ second)			N.S.
THTA	Pitch angle (in degrees)			N.S.
THE+	Pitch angle rate (in degrees/second)			N.S.
ROLA	Roll angle (degrees)	T, F	FxS	S
PHI+	Roll angle rate (degrees/ second)	N.S.		N.S.
PSIA	Heading (degrees)	T, F, S	T, S	T, F
PSI+	Heading rate (degrees/ second)	T, F	FxS	S

Table 6. F-Means for successive levels of S - 1 NM into flight.

	114°	40°	
	1727.865	1734.742	
S.D.	146.608	145.429	Simple
	1735.284	1698.090	
S.D.	145.395	169.978	Complex

Table 7. F-Means for successive levels of S - Runway acquisition point.

	114°	40°	
	1376.326	1477.971	
S.D.	253.308	251.917	Simple
	1450.878	1360.065	
S.D.	264.016	233.419	Complex

Table 8. F-Means for successive levels of S - End of 2 NM turn.

	114°	40°	
	1235.404	1362.324	
S.D.	275.249	272.012	Simple
	1323.083	1227.088	
S.D.	250.124	228.357	Complex

Effects on Vertical Velocity (ROC)

Since vertical velocity (ROC) has a direct effect upon altitude, it seemed appropriate to discuss the results of the analyses on this dependent variable next. Vertical velocity was analyzed at runway acquisition and at the end of the turn but not at 1 mile into the flight. In these two analyses, vertical velocity was significantly affected only for the FxS interaction at runway acquisition. The means and standard deviations are presented in Table 9 . The values for vertical velocity under the four conditions are consistent with the associated altitudes discussed earlier. Again there does not appear to be an obvious explanation for this relationship which, by the way, is weakened substantially for vertical velocities at the end of the turn (no significant effects).

Table 9. F-Means for successive levels of S - Runway acquisition point.

	114°	40°	
	-8.631	-6.078	
S.D.	5.828	5.220	Simple
	-7.075	-8.795	
S.D.	5.380	5.847	Complex

Effects on Distance from Touchdown (LONG)

The dependent variable of distance out from the touchdown marker (LONG) is used to define the second and third locations for analysis and therefore is no longer a variable in these two analyses. It was, however, examined at 1 mile into the flight where the defining variable was the lateral distance from the runway centerline (LATD). The results of this analysis indicated that the longitudinal distance out from the electronic touchdown point on the runway was significantly affected by window availability or field of view (F) and scene complexity (S). The effect of field of view was significant at the $p < .01$ level, with the pilots making tighter turns or alternately initiating their turns earlier when the side window displays were not available than when they were (see Table 10). This seems very reasonable since the sooner or tighter they turn, the sooner they will acquire the runway in the front window display.

Table 10. F-Means - 1 NM into flight

	114°	40°
	39350.334	39199.435
S.D.	616.183	595.495

A similar effect is evidenced under the two scene complexities (significant at $p < .05$), with the tighter or earlier turns being associated with the simple scene, thus resulting in lower LONG values (see Table 11). However, there does not seem to be a similar "strategy" available to explain this effect unless perhaps that the simple scene appears "more distant" or "less well defined" than the complex scene. It was anticipated that the paths flown without the runway in view would be more variable than those in which the runway was visible most of the time. Therefore an analysis of variance was run on the log transform of the variances across trials for the LONG data. No significant effects were evidenced, however.

Table 11. S-Means

	Simple	Complex
	39234.384	39345.384
S.D.	6[illegible]3.[illegible]	539.557

Effects on Lateral Deviation from Runway Centerline (LATD)

Whereas LONG was used to define two of the analysis points, the third, at 1 nautical mile into the flight, was defined by the lateral distance from the extension of the runway centerline (LATD = 8850 feet). Thus this variable was not relevant at this first location but was analyzed at runway acquisition and at the end of the turn. At both these locations, the lateral distance was significantly affected by both the main effects of trials (T) and field of view or side window availability (F). In addition, lateral distance was affected by the TxF interaction at the end of the turn. Table 12 presents the means and standard deviations for the four trials at runway acquisition and show the progressive and significant ($p < .05$) trend to get closer to being lined up on the runway centerline at this point. Since lateral deviation is positive on the side of the initial offset, this indicates that the early trials are tighter than those following, which come out closer to the runway centerline. To look at absolute deviation from the centerline, another analysis was performed with absolute values. Table 13 shows that indeed the later trials have smaller deviations although the differences are smaller. This analysis produced the same significant effects and levels as with the sign of the deviation included.

Table 12. T-Means - Runway acquisition point.

	1421.005	974.790	946.464	707.415
S.D.	1738.484	1561.075	1409.693	1517.424

Table 13. T-Means - Runway acquisition point (absolute values).

	1678.166	1479.433	1285.458	1289.008
S.D.	1487.512	1085.722	1103.910	1059.735

The second variable significant at runway acquisition was field of view (F). This main effect was significant at $p < .01$ in analyses both with and without the signs of the deviations from centerline. Table 14 indicates that the pilots flew closer to the extension of the runway centerline by this point in the approach when they had the runway in view more of the time. Again, turns made without the side window available were tighter than those with the window. The amount of absolute deviation was also greatest without the side window, as Table 15 shows, indicating more variable performance without the side windows available. To test this, an analysis was run of the log-transform of the variances across trials. Table 16 presents the variance means which were significantly different at the $p < .01$ level.

Table 14. F-Means - Runway acquisition point.

	114°	40°
	712.941	1311.896
S.D.	1166.595	1851.580

Table 15. F-Means - Runway acquisition point (absolute values).

	114°	40°
	1055.880	1810.152
S.D.	865.777	1364.009

Table 16. F-Means - Runway acquisition point (variance log transform).

	114°	40°
	12.775	14.164
S.D.	1.414	1.642

Effects had changed only a little by the time pilots reached the end of the design turn at 4.4 NM out. Trials were no longer a significant effect when the direction of the lateral deviation was included in the analysis. When the absolute value was taken however, trials again were significant ($p < .05$), with the error from alignment with the runway centerline decreasing over the first three trials and then showing a slight increase on the last trial (see Table 17). The trials by field of view interaction was also significant ($p < .05$) at this point using absolute deviations. Table 18 presents these results for the means and standard deviations. The means show relatively small and fairly constant errors over trials when the side windows were available. Without the side windows, average deviations from runway alignment were much larger, ranging from about four times greater for the first trial, decreasing to only about twice as large by the third trial. Again there was a slight increase in the deviation on the fourth trial.

Table 17. T-Means - End of 2 NM turn (absolute values).

	938.253	885.481	593.480	701.405
S.D.	1079.357	885.039	709.920	750.805

Table 19. T-Means for successive levels of F - end of 2 NM turn.

	338.536	486.921	370.601	418.561	
S.D.	312.403	490.867	597.063	339.135	- 114°
	1537.971	1284.040	816.358	984.248	
S.D.	1235.914	957.533	751.793	930.283	· 40°

The main effect of field of view significantly affected ($p < .05$) runway alignment at the end of the turn whether the direction (sign) of the deviations were considered or whether absolute values were used. Table 19 provides the means and standard deviations with signs considered and reflect the same trend as the data taken at runway acquisition.

Table 19. F-Means - End of 2 NM turn.

	114°	40°
	60.011	423.222
S.D.	601.219	1479.452

Again the pilots held too tight a turn or initiated it too early when the side windows were not available. Figure 5 shows the spatial dispersion of approaches at this point with lateral deviation from runway centerline being plotted against altitude. While neither group has turned wide enough to end up aligned with the runway, the approaches without the side windows had an average displacement inside the desired arc that was seven times that of the approaches that had the benefit of having the runway in view for most of the approach. It should be noted however, that the difference between the groups is smaller (almost half) than the difference at runway acquisition. Thus the "disadvantaged" group appeared to narrow the difference considerably between these two sampling points.

When the absolute values of deviation from runway alignment are used in the analysis, however, this apparent reduction in the differences between field of view conditions is not substantiated. Table 20 shows that the average absolute difference at the end of the turn is about 752 feet (significant at $p < .01$), almost exactly the same as it was at runway acquisition, where the difference was about 754 feet. This apparent discrepancy can be explained by examining the flight paths under the different conditions, as shown in Figure 4 . For the approaches in which the side windows were not available, and between the two sampling points many of the tracks cross over the runway centerline extension and thus, since signs are considered, begin to average out or nullify errors on the other side of the centerline, therefore reducing the average error. However, it also can be seen that the dispersion of the tracks is relatively unchanged between the two sample points thus maintaining the average absolute error. Apparently, the pilots were unable or not inclined to correct their paths between these two sampling points any more when they had a wider dispersion from the no-side-windows condition than when their paths were more accurately flown with the runway in view most of the time.

Table 20. F-Means - End of 2 NM turn (absolute values).

	114°	40°
	403.655	1155.654
S.D.	448.190	1011.559

The dispersion at the end of the turn was further examined by an analysis of the log-transform of the variance over trials. As in the analysis at runway acquisition, the approaches made without side win-

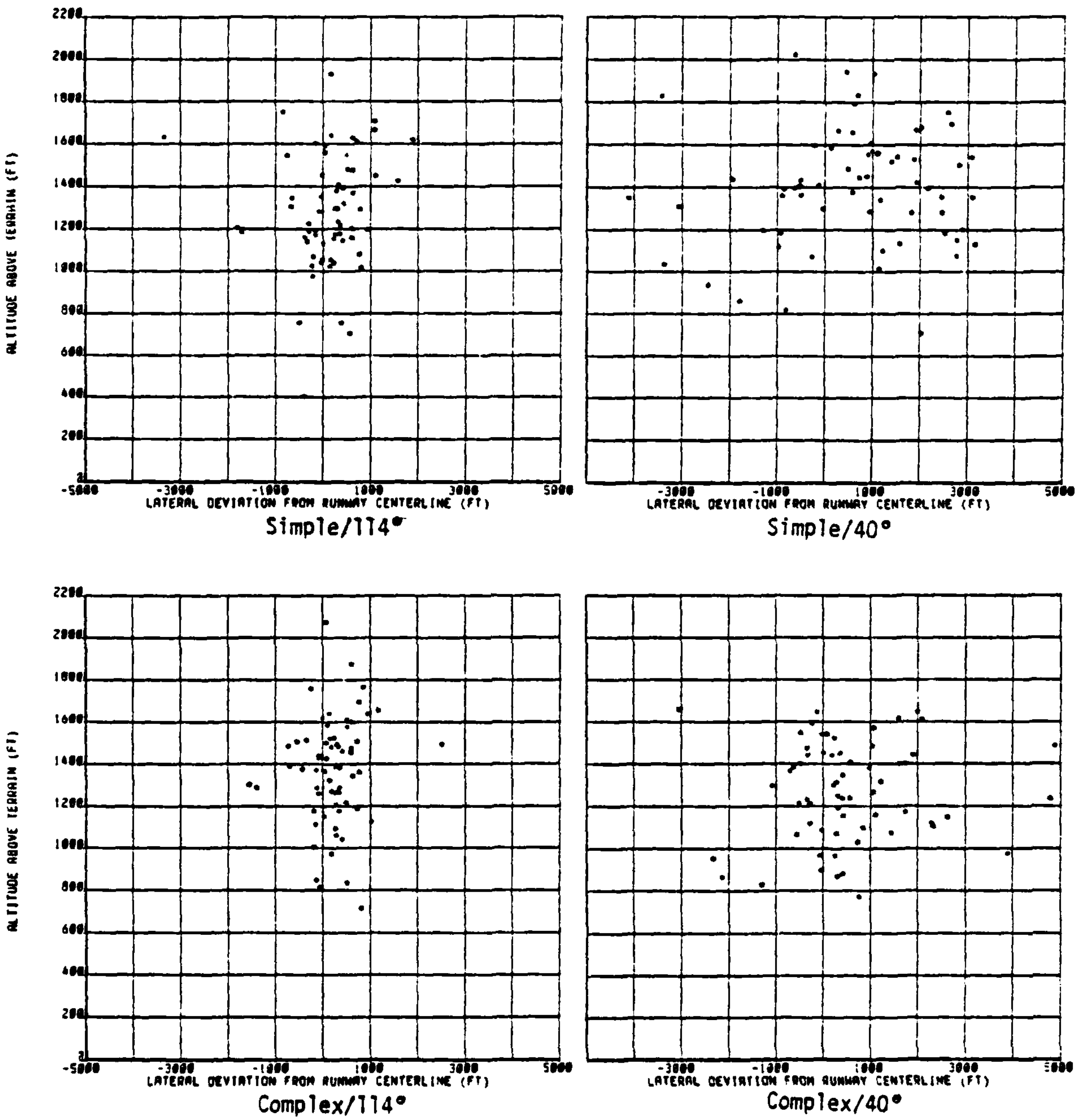


Figure 5. Spatial dispersion (altitude by lateral deviation) of all pilots on the four treatment conditions sampled at the end of the 90 degree turn.

dows avaiable were significantly more variable ($p < .01$) than those made with the runway in view. It can be seen in Table 21 that the average variabilities are reduced by about 6% from those at runway acquisition but the difference in the average variability between the two field of view conditions shows an increase between runway acquisition and the sample at the end of the turn. It is not known (untested) whether this change is significant, but tends to support the view that pilots, when flying approaches that initially do not have the runway in view, are unable or unwilling to correct their flight paths when the runway does become available any more than when the runway is almost always in view.

Table 21. F-Means - End of 2 NM turn (variance log transform).

	114°	40°
	11.530	13.827
S.D.	1.385	1.396

Effects on True Airspeed, Pitch Angle and Pitch Angle Rate

Analyses were run at the end of the turn (4.4 NM out) on true airspeed (VTRU), pitch angle (THTA), and pitch angle rate (THE+). In none of these analyses were there evidenced any significant effects on performance due to the independent variables. This was not surprising since these variables are not as important as some others in executing the 90° turn. However, they were still good candidates for analysis in that earlier studies with straight-in approaches (Kraft, Anderson, Elworth & Larry, 1977) had shown airspeed and pitch to be sensitive measures of performance under conditions of varying external scene quality.

Effects on Roll Angle (ROLA)

Analyses were run on the effects on roll angle (ROLA) at each of the three sampling points. At 1 NM into the flight, it was found that both trials and field of view significantly affected the roll angles flown by the pilots. For trials, significant at $p < .01$, the trend is familiar, with roll angles decreasing over the first three trials and then increasing slightly on the fourth trial. In the means of Table 22, the negative values represent left-wing-down rolls, so the tighter roll angles in the early trials are consistent with the values seen for the lateral deviations across trials discussed earlier. Since the tighter turns seemed to result in poorer eventual alignment with the runway, the trials for roll angle show better performance on successive trials until the fourth.

Table 22. T-Means - 1 NM into flight.

	-10.550	-9.644	-7.769	-8.012
S.D.	5.460	6.290	5.823	5.012

Also consistent with the earlier results on lateral deviations are those involving effects of field of view, also significant at $p < .01$. Again, the means shown in Table 23 show steeper roll angles, and therefore tighter turns, for the initial turns without the runway in view. This would be expected from the data presented earlier on lateral deviation from runway centerline.

Table 23. F-Means - 1 NM into flight.

	114°	40°
	-8.185	-9.803
S.D.	5.710	5.865

By the time the pilots have acquired the runway, the resulting roll angles are quite different however. Although not significantly different, the trend has reversed with a roll angle of -9.1 for the approaches with runway in view compared with an average angle of only -7.7 for the other field of view condition. Almost all of this difference occurs under the simple scene however, with the interaction of field of view and scene complexity being significant at $p < .05$ (see Table 24). These data indicate that at runway acquisition, the pilots had established similar roll angles for approaches to the complex scene whether or not the runway had been visible. On the other hand, significantly different roll angles were being carried for the two field of view conditions under the simple scene. Although the reason for this situation is not clear, it may be related to data discussed earlier in which a similar relationship was found. It was found then that altitude and vertical velocity had this same interaction at this sampling point. The results for roll angle are consistent with these earlier results, assuming that steep roll angles would be associated with lower altitudes and higher descent rates. These results will be referred to again in a later discussion of rates of change in aircraft heading.

Table 24. F-Means for successive levels of S - runway acquisition point.

	114°	40°	
	-9.975	-6.595	
S.D.	5.081	7.310	Simple
	-8.186	-3.795	
S.D.	3.800	6.699	Complex

At the end of the turn, neither field of view nor the interaction of field of view with scene complexity is significant, with the trend shown at runway acquisition no longer in evidence. However, scene complexity now demonstrates a significant main effect, with steeper

roll angles being held under the simple scene conditions ($p < .05$). Table 25 presents the means and standard deviations. At this point, the cause of this effect is not obvious; however, it will be taken up again when heading rate at the end of the turn is discussed.

Table 25. S-Means - End of 2 NM turn.

	Simple	Complex
	-4.365	-3.081
S.D.	5.234	4.090

Effects on Roll Angle Rate (PHI+)

Analyses were run for roll angle rate at 1 NM into the flight and again at the end of the turn. No significant effects were demonstrated in either of these analyses.

Effects on Heading (PSIA)

Analyses were completed at all three points in the turn for the dependent variable of aircraft heading (PSIA). The actual heading values based upon true north were transformed to relate to the longitudinal axis of the runway, i.e., if the heading of the aircraft was aligned with the runway on the approach, the heading used in the analysis would be "zero." Therefore, the pilots began Experiment #1 on a heading of 90° and should have ended it at 0°, aligned on the runway centerline.

At all three sampling points, trials had a significant effect on heading. Table 26 shows that at 1 NM into the flight, the headings for successive trials were reflections of earlier results on lateral deviations and roll angles, with the tighter turns on the earlier trials resulting in heading values closer to runway alignment than those of the later trials ($p < .01$). By the time the pilots reached the point of runway acquisition however, this trend had reversed, with larger headings evidenced now for the early trials. It is reasonable that now that pilots could see the runway, they could also see that they needed to compensate for their early tight turns (or vice versa) by assuming headings that would compensate for these initial errors. This trend, significant at $p < .05$ is shown in Table 27 and is repeated in the results at the end of the turn. Again, the alignment with the runway is better on the later trials and. of course, better overall than at runway acquisition. Table 23 presents these data, significant at $p < .05$.

Table 26. T-Means - 1 NM into flight.

	74.199	77.371	78.023	78.676
S.D.	12.125	9.128	9.919	9.312

Table 27. T-Means - Runway acquisition point.

	17.306	16.292	14.758	14.086
S.D.	10.654	9.844	10.731	10.581

Table 28. T-Means - End of 2 NM turn.

	6.091	4.435	3.275	2.380
S.D.	8.366	7.321	7.545	9.379

Another significant effect found in these analyses was that of field of view. At 1 NM into the flights, the heading values once again indicate that when the pilots do not have the side windows available, they have initiated tighter turns than when the runway was available, thus having significantly smaller headings at this point ($p < .01$). These means, shown in Table 29, lend support to either the "tighter turn" hypothesis or the alternative of the turn being initiated earlier. However, the data on variables discussed earlier (distance out, lateral deviation, and roll angle) seem to more strongly support the former. By the time the pilots have reached the theoretical runway acquisition point, this effect has disappeared, with a slight reversal in the trend. At the end of the turn, heading is again affected significantly ($p < .05$), but with the direction of the means substantiating the reversal trend seen at runway acquisition. The means shown in Table 30 would be consistent with the hypothesis discussed earlier that, at this point, the pilots that started turns that were too tight are now compensating slightly for this earlier "error."

Table 29. F-Means - 1 NM into flight.

	114°	40°
	78.634	75.500
S.D.	9.874	10.494

Table 30. F-Means - End of 2 NM turn.

	114°	40°
	2.519	5.571
S.D.	6.383	9.572

There were also effects on heading angle due to scene complexity. At the first sampling point, 1 NM into the flight, the pilots had acquired smaller headings ($p < .05$) with the simple scene (see Table 31), again tending to substantiate earlier data on distance out which indicated that tighter turns were initially made under the simple scene (refer to Table 11). At the theoretical runway acquisition point we could again hypothesize that there is some compensation

evident for these early turn angles in that the smaller heading values are now associated with the complex scene. In Table 32 the means for heading, though not greatly different, are nevertheless statistically significant at the $p < .01$ level.

Table 31. S-Means - 1 NM into flight.

	Simple	Complex
	75.815	78.320
S.D.	9.952	10.480

Table 32. S-Means - Runway acquisition point.

	Simple	Complex
	17.364	13.856
S.D.	9.992	10.687

Effects on Rate of Heading Change (PSI+)

Analyses were run also on the rate of heading change (PSI+). In these data, negative rate values mean that the value of the aircraft heading itself is decreasing, a condition associated with the left turn. And of course, increasing values either negative or positive, imply a faster rate of change in the heading.

The significant findings, of which there were four, duplicate exactly those found for roll angle (ROLA). This is not surprising, and is in fact encouraging, since roll angle should have a direct effect upon rate of heading change. Thus, the comments made in the discussion of roll angle apply equally to the effects upon heading rate. The two effects significant at 1 NM into the flight were trials (T) and field of view or availability of the side window (F). Both of these effects were significant at $p < .05$ and the means and standard deviations are presented in Tables 33 and 34. A comparison of these results with those of roll angle indeed verify that the direction and magnitude of the means are consistent between these two variables. The reader is referred to the earlier section for a discussion of the practical significance of these effects.

Table 33. T-Means - 1 NM into flight.

	-1.195	-1.124	-0.386	-0.899
S.D.	0.666	0.828	0.643	0.625

Table 34. F-Means - 1 NM into flight.

	114°	40°
	-0.936	-1.116
S.D.	0.668	0.730

At the theoretical runway acquisition point, the field of view by scene complexity interaction was significant ($p < .05$). Again these data are generally consistent with those on roll angle, as are the means under the non-significant trend for the field of view main effect. Table 35 presents the significant interaction means and standard deviations. As mentioned earlier, the interaction means appear to support the data on altitude, vertical velocity, and roll angle at this sampling point. Since much of the data indicate that tighter turns were initiated when the side windows were not available, the heading rates under the complex scene are consistent with this. The reason for the reverse under the simple scene is not completely clear, but may again be a compensation at this point for turns that were too tight early in the flight. Inspection of the flight paths given in Figure 4 would tend to support this somewhat but not overwhelmingly.

Table 35. F-Means for successive levels of S - Runway acquisition point.

	114°	40°	
	-1.137	-0.751	
S.D.	0.605	0.913	Simple
	-0.968	-1.042	
	0.437	0.804	Complex

At the end of the turn, the effect of scene complexity is significant for heading rate ($p < .05$). As with all of the significant effects on heading rate, these are consistent in direction and magnitude with the data for roll angle. The means shown in Table 36 indicate slightly lower heading rates under the complex scene. These data, as well as those on roll angle, would support a hypothesis that alignment with the runway is achieved sooner with the complex scene than under the simple scene condition. Inspection of all the flight paths, including those plotted in Figure 4 , seems to support this hypothesis.

Table 36. S-Means - End of 2 NM turn.

	Simple	Complex
	-0.528	-0.386
S.D.	0.692	0.500

CONCLUSIONS - EXPERIMENT #1

Trials

In this experiment, the pilots had a short training session prior to the test flights. It was not intended that this training should bring all pilots up to some criterion level, but was primarily for the purpose of familiarization with the 747 cab and its instrumentation, the feel of the simulator and its control responses in "flight," and experience with the display channels and the computer generated scenes. Therefore it was not unexpected to find some learning effects across trials in the experimental test flights. A fairly consistent pattern was evidenced and, as will be shown later, it carried through in some instances in the other experiments.

For experiment #1, the effect of successive trials had two consistent characteristics for most of the significant dependent variables:

a. Performance improved over the first three trials;

b. There was a slight decrease in performance on the fourth trial.

Improvement in performance over trials generally consisted of changes in the dependent variables which were associated with making wider turns, resulting in better alignment with the runway at the end of the turn. The slight decrement in performance of the last trial is characteristic of this type of test situation where the task repetitions are fixed in number and consecutive.

Field of View

This independent variable has also been defined as availability or non-availability of the side window scenes in the simulator. Although these both refer to the same two conditions, in this study they would not necessarily always be identical. For instance, the 114° field of view might be centered around the straight ahead reference in another simulator, and coincidentaly the side-windows-available condition might involve a very different field of view, such as if the forward window was not involved at all. In the task of experiment #1, that of a 90° left turn to alignment with the runway, both aspects of this variable could well have a significant effect upon performance independent of the other aspect. Obviously, the availability or non-availability of the scene out the side window could be important in making a left turn when alignment with the runway is desired at the end of the turn. It is perhaps less certain, but also possible, that the size of the field of view itself might be important, as some other investigators have found (Clark, 1975, Cyrus, 1978). In the present experiment, these two factors are confounded with each other, so the results apply to the combination of side window availability and field of view.

There were two major characteristics that typified the significant effects of this variable combination upon simulator flight performance:

a. Without the side window (greater FOV) available, the pilots initiated tighter turns, resulting in poorer alignment with the runway at the end of the turn, and more often requiring corrective actions later in the flight;

b. Without the side window (greater FOV) available, the pilots fly paths that are significantly more variable than when they have the runway in view most of the time.

Both of these significant trends support the hypothesis that the addition of the side window scenes (or wide field of view) has a positive impact upon the pilot's ability to fly a 90° turn onto final approach. Of course, the question of whether the side windows should be provided on any particular simulator can only be resolved by consideration of relative costs, the training requirements, the effects on transfer of simulator training to actual flight performance and/or training, and the tradeoffs between these factors.

Scene Complexity

Although not demonstrating as many significant effects as field of view, scene complexity did have an impact on roll angle and heading rate, as well as having a significant interaction with field of view in several instances. The primary conclusions to be made from the significant main effects of scene complexity were:

a. When the pilots have the simple scene to fly to, they initiate slightly tighter turns, resulting in somewhat poorer alignment with the runway at the end of the turn.

b. At runway acquisition, corrective actions for the initial tight turns appear to take place under the simple scene, with yet more but different corrections taking place at the end of the turn.

These effects, though significant, are small and occurred infrequently. Therefore it is felt that substantiation of these results through replication is necessary before these trends could be called generalizable effects.

Field of View by Scene Complexity

There were a larger number of analyses in which the interaction of field of view and scene complexity were significant. The direction and magnitdue of the values for the four conditions in this interaction are quite consistent for the various dependent variables which were significantly affected by this interaction. However, the interpretation of the trend is not obvious. For three of the four conditions (simple/114°, complex/114°, and complex/40°) the relative values support the trends seen in the significant main effects of these two variables. But the fourth condition, simple scene with 40° field of view, generally has values in opposition to those which would be predicted from the main effects. Of course, this inconsistency is what makes the interaction

significant in itself. From the individual action of both of the main effects, it would be expected that, with the simple scene and 40° FOV, the pilots would fly tighter turns with lower altitudes, higher roll angle and lateral displacements, greater descent rates, and increased heading rates. The results on the other hand, indicate just the opposite.

A very tentative hypothesis for this interaction would be that, under the reduced visual content or cues due to the simple scene and reduced FOV, the impression or feeling of motion may be reduced with the result that the pilot initiates a slower more gradual turn. This seems reasonable from one viewpoint, but the reverse relationship could be argued from another viewpoint, so this premise must await more definitive experimental tests for its resolution.

EXPERIMENT #2

FIELD OF VIEW AND SCENE COMPLEXITY - STRAIGHT-IN APPROACH

We would expect stimulation in the visual periphery to have an effect on the observer's appreciation of motion through space as experienced by the pilot of an airplane on the approach to the runway. The pilot would fixate critical details of the image of the runway in front of the airplane (on a straight-in approach), i.e., the head and eyes would be positioned so that the image of these details fell on the foveal area of the retina where resolution (acuity) of fine detail is highest. The ability to perceive fine detail falls off sharply as the image to be resolved is moved away from this central foveal area. Jones and Higgins (1947), using Landolt C's, found that at 30 arc minutes from the center, visual acuity ($1/\alpha$, where α is the angular size of the smallest perceptible critical detail) had fallen to 50 percent of what it was at the foveal center.

The sensitivity for perception of relative motion also decreases from the central visual field to the periphery, as a linear function of distance (McColgin, 1960). However, the perception of motion in peripheral vision may play an important role in our judgment of relative speed and, in the case of extrapolation of our path in an automobile or an airplane, for example, the point and time of impact with anything intercepting that path.

Obviously, the information contained in the changing image presented to the center of the visual field is of greatest importance in a visual approach to landing. The question to be answered by this second experiment is, "Does the information available through the left portion of the front window or through the side window on the pilot's side of the cockpit (in a large commercial aircraft) contribute significantly to the quality of pilot performance in an approach to landing when the approach is straight in?" If there is some effect, is this effect related to scene complexity? A seemingly reasonable assumption would be that an extremely simple scene (with relatively undifferentiated fields to the sides) would provide few useful cues of motion to the peripheral visual field.

METHOD - EXPERIMENT #2

Experiment #2 used the same simulator (flight Crew Training Redifon 747) as in Experiment #1 and the same 16 Air Force Military Airlift Command (MAC) pilots, each of whom made four touch-and-go landings under each of the four experimental conditions: 2 scene types (simple and complex); and 2 viewing field sizes (with and without the left front window or the side window), for a total of 256 landings.

All approaches began 4.7 nautical miles (NM) from runway threshold at 1328 feet altitude with the aircraft trimmed for a 2.5° glide slope descent. These initial conditions were set up by the instructor pilot in the right seat before turning control over to the experimental pilot.

The latter was told to proceed straight in to a touch-and-go landing at the 1000 ft. mark with a minimum descent rate at touchdown. Each experimental pilot was told of the study conditions (field of view and scene complexity) and of the four replications for each combination of conditions.

The presentation order of the conditions was the same for each experimental pilot who was informed of the combination to be used prior to each approach. Each pilot was assured of anonymity in the reporting of the results and that performance would not become part of any records, official or unofficial, other than those needed by the experimenters for valid interpretations of the data, e.g., relationships between visual skills and performance under the various experimental conditions.

The dependent measures of pilot performance were the same as those used in Experiment 1 (see page 10) except for those which are not applicable to one study or the other.

RESULTS AND DISCUSSION - EXPERIMENT #2

Table 37 lists the results of analyses of variance performed on the data from Experiment 2. At longitudinal distances 12,000, 6,000, and 3,000 feet from glideslope intercept with the runway (1840 ft. beyond runway threshold) analyses were performed on six dependent variables. The first variable, altitude, was not significantly changed by scene complexity (S), or by availability of the larger field of view at a distance of 12,000 ft. out. At 6,000 and 3,000 ft. out trial by scene complexity interactions were significant and at 6,000 ft. scene complexity as a main effect reached significance. In a separate analysis which treated distance as an added independent variable, trial by scene complexity and trial by distance interactions were statistically significant. Scene complexity interacted with distance such that reduced variability was shown for complex scenes further out compared simple scenes. Distance as a main effect is shown to be significant but this constitutes no surprise finding since on the approach altitude must drop as a function of decreasing distance.

Glide Slope Deviation

Glide slope deviation is affected by scene complexity at all three distances out and when distance is treated in the analysis of variance as an independent variable this deviation is significant both as a main effect and through interaction with distance. The effect of distance out on glideslope deviation is immediately apparent in the altitude versus distance data.

Rate of Climb

Data show significant differences due to field of view and to scene complexity at 12,000 ft. distance out. At 6,000 ft. out field of view no longer appears significant and scene complexity only as an interaction with trials. At 3,000 ft. out scene complexity is significant as a main effect and as interactions with field of view and

Table 37. Significant effects on dependent variables in Experiment #2.

ACRONYM	DEFINITION	LONG = 12,000 ft.	LONG = 6,000 ft.	LONG = 3,000 ft.	DISTANCE AS ADDED VARIABLE 12, 6, 3 K ft.	TOUCHDOWN
H	CG altitude (ft.)	N.S.	S TXS	TXS	TXS D TXD SXD	N/A
GSPE	Glideslope deviation (ft.)	S	S	S	S D SXD	
GSCAL	Calculated G.S. deviation (ft.)	N/A	N/A	N/A	N/A	N.S.
LONG	Longitudinal distance out from 1840 ft. mark (ft.)	/A	N/A	N/A	N/A	N/A
LATD	Lateral displacement from runway centerline (ft.)					S
ROC	Vertical velocity (ft/sec.)	F S	TXS	S SXF SXF	T TXF FXS D SXD TXSXD	N.S.
VTRU	True airspeed (ft/sec.)					N.S.
THTA	Pitch angle (degrees)	N.S.	N:S.	FXS	TXF D SXD TXSXD	N.S.
THE+	Pitch angle rate (deg/sec.)	N.S.	F	N.S.	FXD SXD	TXS
AOA	Angle of attack (degrees)					N.S.
PL#2	Power lever angle on engine #2 (degrees)	N.S.	TXS	TXF	FXS D	N.S.

with trials. When all three distances are treated as an added variable, trial is significant as a main effect and as an interaction with field of view. Scene complexity in this analysis interacts with field of view and with distance as well as in a second order interaction with trial and distance. Distance is also significant as a main effect.

Pitch Angle

Pitch angle is not significantly affected by field of view, scene complexity, or trial at the 12,000 and 6,000 ft. distances, but it is significant as an interaction between field of view and scene complexity at 3,000 ft. out. Distance, trial by field of view, scene complexity by distance, and trial by scene complexity by distance are significant when distance is treated as an added variable.

Pitch Angle Rate

Pitch angle rate in degrees per second was not significantly affected at 12,000 and 3,000 ft. distances but was affected by field of view at the 6,000 ft. distance. With distance as an added variable it had a significant effect on pitch angle rate as an interaction with field of view and with scene complexity.

Power Lever Angle

Power lever angle on engine no. 2 was not affected by the independent variables at 12,000 ft. distance, but it was affected by trials in their interaction with scene complexity at 6,000 ft. and with field of view at 3,000 ft. Distance was a significant main effect in the analysis using all of the three distances as levels of an independent variable; field of view interacted with scene complexity to affect power lever angle on engine no. 2 in this analysis.

At touchdown 10 measures of performance were used in analyses of variance tests of significance. They included a) calculated glide slope deviation, b) longitudinal distance out from the 1840 ft. mark (runway/glide slope intercept), c) distance from visual touchdown mark (1000 ft. from runway threshold), d) lateral displacement from the runway centerline, e) rate of climb, f) true airspeed, g) pitch angle, h) pitch angle rate, i) angle of attack and j) power lever angle on engine no. 2. Of these ten dependent variables, only two were significantly affected by the experimental variables: scene complexity had a significant effect on lateral displacement from the runway centerline, and trial by scene complexity was significant as an interactive effect on pitch angle rate.

CONCLUSIONS - EXPERIMENT 2

Experiment 2 was designed to answer questions about the influence of the field of view on pilot performance in the approach and landing phase of flight when this phase does not involve turns. Unlike Experiment 1 where the approach was terminated just inside the outer marker, in this experiment data acquisition included the measurement of selected flight parameters at touchdown, in addition to measures taken at dis-

tances of 3,000, 6,000, and 12,000 ft. from the nominal touchdown point on the runway.

These measures included altitude, glide slope deviation, rate of climb (descent), pitch angle, pitch angle rate, and power lever angle on engine no. 2.

Vertical Velocity

Vertical velocity is a very sensitive measure of pilot performance on the approach to landing since the control column and throttle manipulation must be well coordinated for smooth flight and this is reflected in descent rate. Combining all independent variables except trial number (order) the analysis reveals a significant effect ($p < .01$) for this variable (see Table 38), but the observed difference seems to lie almost completely with the first of four trials where the descent rate is approximately one foot per second less than in trials 2 through 4. Though statistically significant, this finding has no immediately apparent practical significance.

Table 38. T-Means

	-11.277	-12.179	-12.392	-12.589
S.D.	4.232	4.071	4.387	4.528

When these four trial means are divided according to fields of view (114° vs. 40°) there is an apparent significant ($p < .05$) interaction, though field of view is not significant as a main factor. As Table 39 shows, while the means for the first trial vary little from their average, the differences for trials 2 and 4 are considerably larger for the two fields of view. Though our statistical analysis suggests that this interaction is not due merely to chance, it is difficult to reason our way to a plausible hypothesis for such a result.

Table 39. T-Means for successive levels of F

	-11.518	-11.555	-12.589	-11.849
S.D.	4.155	4.057	4.209	4.597
	-11.036	-12.802	-12.194	-13.328
S.D.	4.316	4.009	4.572	4.356

We've seen that field of view did not have a significant main effect on vertical velocity (VV); the same is true for scene complexity. However, the two individual factors do act together to affect vertical velocity significantly as shown in Table 40. Descent is slower with the wide (114°) view of the simple scene, intermediate with the narrow (40°) view of the complex scene and most rapid with a wide view of the complex scene or a narrow view of the simple scene.

Table 40. F-Means for successive levels of S

	-11.031	-12.667
S.D.	4.709	5.038
	-12.725	-12.013
S.D.	3.584	3.600

The mean vertical velocity for the three distances out (12,000, 6,000 and 3,000 ft., Table 41) show a break between 12,000 and 6,000 ft. which is assumed to be related to the pilot's desire to begin leveling off in preparation for a smooth letdown to the runway. The descent rate is affected not only by distance but also by scene complexity interacting with distance as shown in Table 42. The descent rate as a function of distance for simple scenes starts higher than with the complex scenes and slows more rapidly and consistently.

Table 41. D-Means

	-13.377	-11.584	-11.367
S.D.	3.198	4.525	4.818

Table 42. S-Means for successive levels of D

	-13.835	-12.918
S.D.	3.466	2.845
	-11.399	-11.769
S.D.	5.280	3.628
	-10.373	-12.420
S.D.	5.206	4.155

There was no significant interaction of trials with distances but when the data are analyzed to permit the influence of another variable, scene complexity, it shows an interactive influence with these two variables (T and D). Scene complexity shows a more prominent decrease in rate of descent in the first three trials at the nearest distance (3000 ft.) in Table 43. One of the most difficult aspects of this approach to data analysis is that conclusions based on inspection of the data are appropriately suspect in that the cause is assumed from the observation of the effect. In the present instance, there was no clear reason to anticipate a TXSXD interaction before the statistical analysis indicated its existence. We can conclude only that some of the experimental variables require an experimental design with better controls for the unequivocal assessment of the influence of the main factors in the study.

Table 43. Means for combinations of TSD (T varies first, then S, etc.)

	-12.944	-18.876	-14.254	-14.259	Simple	D = 12,000
S.D.	3.546	3.522	3.483	3.304		
	-12.540	-12.828	-12.835	-13.469	Complex	
S.D.	2.982	2.446	2.877	3.088		
	- 9.267	-11.584	-12.359	-12.386	Simple	D = 6,000
S.D.	4.740	4.496	4.186	6.878		
	-12.132	-11.962	-11.460	-11.520	Complex	
S.D.	3.272	3.052	4.552	3.584		
	- 9.555	- 9.786	- 9.886	-12.026	Simple	D = 3,000
S.D.	4.408	5.131	5.905	5.129		
	-11.226	-13.035	-13.559	-11.860	Complex	
S.D.	4.875	4.168	3.534	3.685		

Pitch Angle (THTA)

The pitch angle was not significantly affected by trial order (T) or field of view (F) as main effects but these two experimental variables were significant when acting together (Table 44). The means across the four trials appear to be of relatively equal size with the larger (110°) field of view but drop from first to last trial with the small field of view.

Table 44. T-Means for successive levels of F

	2.896	2.967	2.613	2.948
S.D.	1.690	1.770	1.867	1.729
	3.026	2.661	2.737	2.225
S.D.	1.716	1.825	1.753	1.949

Distance out had a significant effect on pitch angle (Table 45); the nose of the airplane was brought up slightly as the distance from touchdown decreased. This of course is expected in a standard approach in a Boeing 747.

Table 45. D-Means

	2.223	2.974	3.080
S.D.	1.694	1.848	1.733

Scene complexity interacts significantly with distance in their effect on pitch angle. As Table 46 shows the pilots tend to bring the nose up more with the decreased distance when the field of view is wide than when it is narrow. This trend was evident in the data for rate of descent with lower pitch angle corresponding to higher descent speeds.

Table 46. S-Means for successive levels of D

	2.159	2.287
S.D.	1.685	1.707
	3.020	2.929
S.D.	2.044	1.636
	3.271	2.889
S.D.	1.845	1.597

As in the case of rate of climb as the dependent variable there is an interaction among trial order, scene complexity and distance out as the affect pitch angle. In this case also the pitch angle mirrors the descent rate and is most apparent in the first three trials, wide view, and 3000 ft. (Table 47).

Table 47. Means for combinations of TSD
(T varies first, then S, etc.)

	2.320	2.161	2.193	1.963	Simple	D = 12,000
S.D.	1.617	1.812	1.688	1.678		
	2.330	2.511	2.275	2.032	Complex	
S.D.	1.732	1.666	1.610	1.858		
	3.630	3.129	2.671	2.649	Simple	D = 6,000
S.D.	1.888	1.904	1.904	2.375		
	2.899	2.935	2.939	2.942	Complex	
S.D.	1.603	1.591	1.767	1.654		
	3.423	3.467	3.344	2.849	Simple	D = 3,000
S.D.	1.498	1.969	1.910	1.979		
	3.163	2.678	2.629	3.085	Complex	
S.D.	1.501	1.658	1.830	1.367		

Glide Slope Deviation (GSPE)

The glide slope deviation (GSPE) is affected by scene complexity and distance out in an interactive fashion. The expected decrease in deviation from the 2.5° glide slope as distance from touchdown lessens is more pronounced with the simple scene than with the complex scene (see Table 48). The general slope of the descent path is steeper with the simple scene.

Table 48. S-Means for successive levels of D

	104.504	74.843
S.D.	80.721	55.709
	78.356	48.921
S.D.	54.307	38.719
	41.076	31.558
S.D.	30.549	26.143

The distance from touchdown, as mentioned in the preceding paragraph has a predictable effect on glide slope deviation, and it was expected that it would be statistically significant. The means are shown in Table 49.

Table 49. D-Means

	89.673	63.639	36.317
S.D.	70.793	47.461	28.773

Other than distance out only one main effect proved to be significant, that of scene complexity (S). The glide slope deviation mean for the simple scene was significantly greater than the corresponding mean observed for the complex scene (Table 50). It appears that the experimental pilots were aided by information which was available in the complex scene but not in the simple scene.

Table 50. S-Means

	74.645	51.774
S.D.	64.243	44.158

Power Settings

The power settings on the engines, in this case, no. 2, (PL #2) is, of course, correlated with other dependent or pilot performance variables. The variability associated with experimental conditions other than distance from touchdown point is so small that the very small differences observed for the three distances proved significant ($p < .01$). The slight increase in power setting from the 12,000 ft. distance to that for 6,000 ft. and subsequent reduction of power to the level shown in Table 51 for 3,000 ft. has not as yet been explained. The field of view interaction with scene complexity is significant at the $p < .05$ level for this power setting, but the finding does not clarify the meaning of such small differences between means as seen in Table 52.

Table 51. D-Means

	76.366	77.553	75.720
S.D.	3.078	4.361	4.563

Table 52. F-Means for successive levels of S

	77.183	76.128
S.D.	4.475	4.452
	76.304	76.570
S.D.	3.548	3.883

Altitude

The dependent variable most easily identified as a critical measure of pilot performance on the approach is altitude (H). A significant ($p < .05$) trials by scene complexity interaction is shown in Table 53 where altitude increases monotonically with trial order and the simple scene, while with the complex scene there is an increase over the first two trials but a drop over the last two. The reason for this is not apparent.

Table 53. T-Means for successive levels of S

	270.120	282.539	288.373	314.195
S.D.	182.611	196.604	197.538	213.975
	295.024	321.355	303.124	297.578
S.D.	182.923	189.088	188.025	186.899

Distance (D) is of course strongly related to altitude on an approach (Table 54) but so also in the present study are the interactions of distance with scene complexity and with trial order. Although interaction of scene complexity with distance is shown to be statistically significant, the slight trends in the the means can have little practical meaning (Table 55). Trial order also interacts with distance ($p < .05$) but not in any way from which clear conclusions may be drawn (Table 56).

Table 55. S-Means for successive levels of D

	521.943	534.668
S.D.	132.413	92.403
	234.401	262.594
S.D.	91.579	59.176
	110.077	115.549
S.D.	46.884	38.498

Table 54. D-Means

	528.305	248.497	112.813
S.D.	114.129	78.233	42.900

Table 56. T-Means for successive levels of D

	503.960	535.145	527.370	546.747
S.D.	103.966	114.274	116.731	119.298
	234.819	252.504	249.770	256.896
S.D.	77.619	80.130	74.018	81.052
	108.936	118.193	110.105	114.017
S.D.	40.568	42.912	39.433	48.514

Touchdown Data

A separate analysis was performed on the pilot performance data at touchdown. Only two experimental variables had a significant ($p < .05$) effect on performance. Scene complexity had a significant effect on lateral deviation from runway centerline on touchdown averaging 27 ft. off for the simple scene but only 18 ft. average for the complex scene (Table 57). This suggests that the additional details in the complex scene can be used to an advantage in lining up with the center of the runway (no runway centerline was available to the pilot).

Table 57. S-Means

	Simple	Complex
	27.617	18.146
S. D.	35.019	26.756

The other significant effect was an interaction between trial order and scene complexity (Table 58). On the first, third, and fourth trials pilots, on the average, were lowering the nose on touchdown and raising it on the second trial when flying to the simple scene; with the complex scene this lowering of the nose occurred on the second and fourth trials where the first and third trials showed a tendency to have the nose being raised.

Table 58. T-Means for successive levels of S

	-0.355	0.149	-0.002	-0.051
S.D.	0.966	0.732	0.851	0.779
	0.229	-0.178	0.271	-0.047
S.D.	0.732	0.920	0.873	0.847

EXPERIMENT #3

RUNWAY SURROUND COLOR AND SCENE COMPLEXITY - STRAIGHT IN APPROACHES

All of the seven major manufacturers of computer-generated images as adjuncts to flight crew training simulators offer to the military and to civil air transport organizations the capability of having color in their visual simulation systems. In the day systems and in one of the night-only systems, there is a large range of colors. The three color primaries are reproduced and additive mixtures of them can provide a large proportion of the spectral colors in the CIE diagram. Other night-only systems represent colors with two phosphors and additive mixtures will provide green, yellow, amber, red and an approximation of white. A third alternative is to produce a monochrome system with a single phosphor CRT. However the addition of more color refinements are associated with large increases in cost.

As recently as November 1979, scientists and operational personnel agreed that there were no critical data which proved or disproved the need for color. This occurred at a workshop assembled at the First Interservice/Industry Training Equipment Conference in Orlando, Florida. The conference concurred that the esthetic preference for color was not a cost-effective reason for having full color visual simulation systems.

The effort represented by the third experiment in this AFOSR contract was not envisioned as the critical experiment to answer the question of the need for color. It was an undertaking to determine whether a specific aspect of the perception of color in the human visual system may be an advantage or a disadvantage to pilots in approaches and landings. In the computer-generated images colors can be assigned to a field which will clearly differentiate it from an adjacent field or ground plane, adding to the realism and the identification of specific terrain features. The color supplements photometric contrast and can be used effectively to reproduce some of the changing luminous characteristics imposed by atmosphere and time of day. However, in the CGI system it may produce some uniquely troublesome aspects. Saturated colors may be assigned to specific items within the scene and, if the instructor pilot elects to eliminate all atmospheric effects between his aircraft and the ground, the appearance of the ground will then be that of a supersaturated display very much like those used in animated cartoons. Intensely saturated scenes are unrealistic as the atmosphere desaturates real world air-to-ground scenes. Saturated images in CGI displays may also produce false spatial localization of colored surfaces, and such spatial localization may differ markedly among pilots.

Pure color, as generated on the cathode ray tube, may also appear like a film color filling the surface bounded by the adjacent objects or edges. For example, if one places before one eye a short paper tube and looks at a homogeneous color, the color will appear to be at the end of the tube and not at the distance it actually is in the scene. In other words, it is perceived as a film color at the end of the tube. In

the CGI system, the color per se may not have the same perceived location in space varying under such conditions as the dominant wavelength of the hue and sharpness of the pattern encompassing that hue. However, as the scene detail decreases, the possibility of a change in the perceived location of the color in space may increase.

Two characteristics of the human visual system may also contribute to a different perception of a color's spatial localization. The human eye is not fully color corrected, so red comes to a focus on the retina with less lens change than does blue. For the theoretical eye, 1.5 diopters of change are necessary to shift the best focus from red to blue. This chromatic interval differs from one individual to another. In the last 15 years, a series of investigations pointed out that in the binocular perception of color, there is a stereoscopic effect entirely due to the hue of the color. For one half of the population the long wavelength colors are seen to be advancing toward the individual relative to the short wavelength colors. For the other half of the population, wavelength relationship is inverted (Kraft & Anderson, 1973). This phenomenon, called chromostereopsis by Vos (1960) will mean that in a virtual image display saturated colors will be seen to have differential stereoscopic depth which changes from one individual to another. This experiment included a measurement of this individual differences among pilots and presented in the special data bases a capability of setting a blue/black runway surrounded by colors of long wavelengths in one instance and of short wavelengths in the second.

The computer-generated image with its infinity display has some charactersitics that may be ideal for the study of the influence of chromostereopsis on perception. The CRT is viewed through an optical window in which all rays are collimated to a distance beyond 10 meters. The virtual image is perceived as being at infinity and there is unit magnification of the scene by the optics. An empirical study showed that this design results in an average object size error of .11 percent for altitudes up to 20,000 ft. Pattern, location and movements of objects are within similar specification. There are no shadows which would enhance the perceptual localization of objects.

Chromostereopsis varies directly with the degree of saturation. in stereoscopic presentations (Kraft 1973). Saturation can be varied by the instructor pilot by the type of atmosphere he chooses to use in the scene. The pupil size varies inversely with the retinal illuminance and at lower brightnesses is modified by the Stiles-Crawford effect (DeGroot & Gebhard, 1952). For example the highest brightness in the Compuscene is six foot lamberts; this is associated with an effective pupil diameter of 3.33 millimeters. The illuminance used in this experimental investigation averaged .9 foot lambert and the associated effective pupil size is about 4 millimeters. and the natural pupil size about 4.64 millimeters. The effects of this larger pupil diameter are to increase the chromatic aberration while decreasing the diffraction effects.

The data from Leibowitz (1952) are illustrative of findings by other investigators, that acuity reaches a maximum value for apertures between 2.5 and 4.0 millimeters. Presumably the fairly constant level of acuity as the aperture increases from 2.5 to 5 millimeters represents

a balance between the effects of diffraction with smaller apertures and the increase in the effects of optical aberrations with larger apertures. Another aspect of the larger apertures is that the individual differences are relatively large in this range. The various subjects used by Cobb, 1914 and '15 and Coleman, 1949 showed marked variations in acuity scores.

These data suggest that with the larger apertures physiological and psychological factors are of major importance. Among these factors are presumably the following: a) coarseness of the retinal mosaic, b) refractive errors, c) accuracy of accommodation, d) aberrations of the eye, e) the specific criteria used by the subject to judge whether the elements of the test pattern have been resolved, and f) variations from one experiment to another in matters of test pattern, target contrast, field intensity and experimental procedure. Foveal and 10° extra-foveal hue discrimination differ markedly between .95 foot lamberts and 9.5 foot lamberts according to Weale (1951). In consideration of the latter and the fact that we were operating around .9 foot lamberts a special matching method was used to establish a reference for the colors that were actually being displayed.

METHOD - EXPERIMENT #3

Stratification by Chromostereopsis

The stratification of the 15 pilots into three groups by their chromostereopsis threshold as measured with the ARC test provided a nearly equal separation along this dimension. This is clearly illustrated in Table 2. The standard deviations shown in this Table also indicate how closely the three groups were matched as to the dispersion of their chromostereopsis scores. Statistical tests indicate that the neutral group is different from the two other groups ($t = 7.69$, p .01). The stratification of the groups results in about equal average age. However the hours of flight experience is greatest for the blue advancing group, second for the neutral and least for the red advancing group. The very large standard deviations of the flight hours indicate that these differences would not be statistically significant, however we have no pretest of whether there is a practical significance in this difference.

The three groups in terms of visual acuity at "far," are above the clinical normal and are not significantly different from each other. The achromatic stereo skills are very high for the neutral and red advancing groups and a 33 arc second level for the blue advancing group. The administration of the Farnsworth 100 hue test combined with scoring the results in terms of total number of errors indicate that all three groups have good color discrimination and would also not differ from each other in this dimension.

The division of the 15 pilots into the three stratifications by chromostereopsis has at least provided us with two distinctly different groups, without large differences in age, flight hours, visual acuity, color discrimination and stereoscopic skill.

Experimental Design

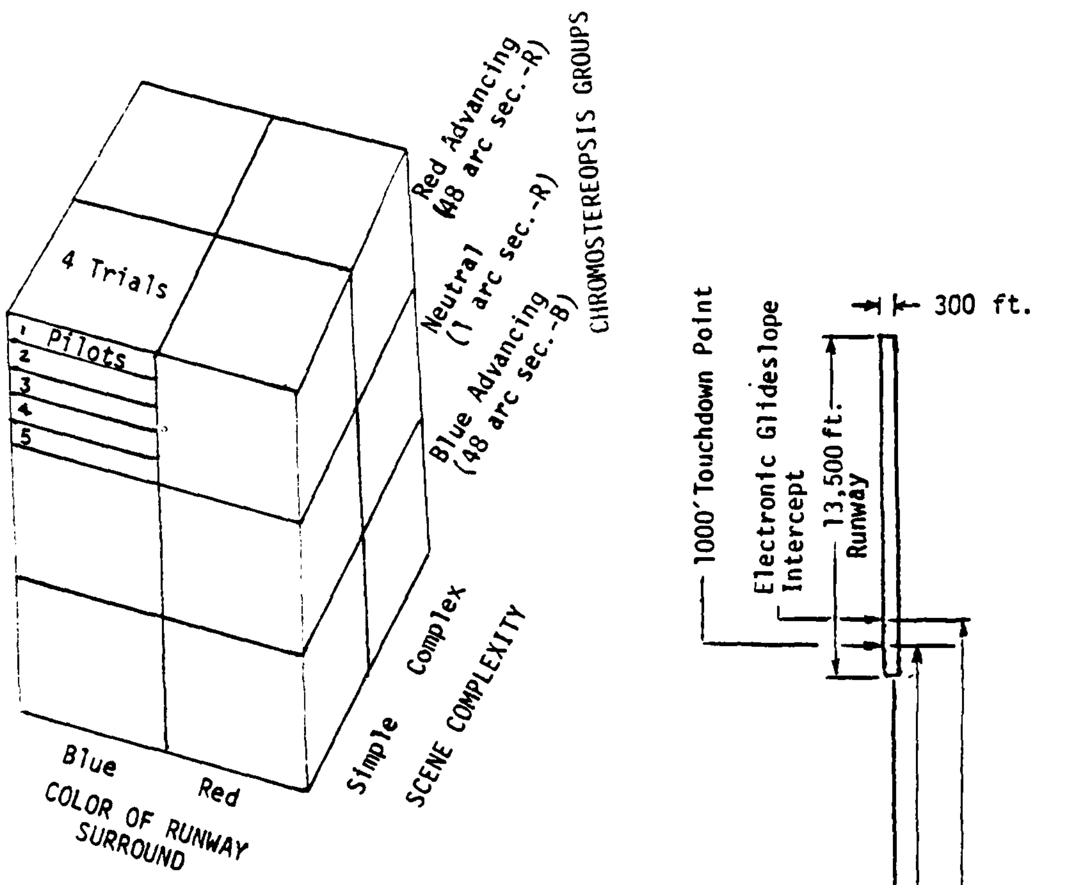
The experimental design used was a 2 x 2 x 4 x 3 x (5) factorial with the five pilots nested within the three chromostereopsis groupings. This arrangement of variables is shown in Figure 6. The diagram on the left illustrates the interrelationships of these variables and the right hand diagram showing a planned position illustration of the letdown path to the simulated Moses Lake runway. Again, in this experiment the 13,500 ft. long 300 ft. wide runway was blue/black macadam and had no markings on it. The simulator recording device used as a zero reference, the electronic glideslope intercept with the runway. This intercept is 1840 ft. down runway from the runway threshold and 4.7 nautical miles from the outer marker. The beginning of the trials was as the outer marker and 4.7 nautical miles from this zero point along an aircraft heading of 321.

The instructions asked the pilot to leave the outer marker at an altitude 1330 above ground and proceed on a straight-in approach to the visual touchdown reference point. Although this was not marked, it was designated as being 1000 feet from the threshold down the runway. So by instructions, the distance to cover was 27,733 ft. or 4.56 nautical miles. The instructions also advised that the beginning altitude was 1330 feet above ground and the task was to proceed on to touchdown. The aircraft's reference altitude is actually 14 feet below the eye reference point and we rounded to 1330 ft; the actual eye reference point is 1328. So the pilot following instructions precisely would have remained on a straight-in glideslope of 2.7° from 1324 (aircraft reference) altitude until touching down at the 1000 ft. goal. The touchdown reference altitude was 16-1/2 ft. and the eye reference 14 ft. above that, or approximately 30 ft. when the aircraft had full weight on all gears.

The other scene parameters set into the Compuscene at the beginning of these trials were visibility of 30 nautical miles, runway visual range of 200,000 ft., cloud bottoms at 5000 ft. and cloud tops at 10,000 ft.

Specification and Control of Color

The authors of this report desired to specify the color in such a fashion that other research investigators could duplicate it at different locations and with similar equipment. The general Electric Compuscene 4000 uses, as a source of its illuminance, a RCA shadow mask cathode ray tube that uses three primary phosphors. Figure 7 shows the topography of perceived brightness superimposed on a standard CIE chromaticity chart. The triangle encloses the area of colors and brightness levels reproduced with a tri-color phosphor tube. Although this is the primary source of the colors for the Compuscene, the perceived color is modified by the illuminance passing twice through a beam splitter. Therefore CRT color specifications would not suffice as a specification without including the infinity display. In addition to this the computer programs can generate a large number of hues, chromas and values depending upon the selection of the magnitude of the three primaries. These same selection of primary values may not generate the same color



SCENE PARAMETERS

Visibility, 30 NM
RVR, 200,000'
Cloud Bottoms, 5000'
Cloud Tops, 10,000'
Day Scene, MWH, G.E. Compuscene = Complex
Runway only = Simple Scene

Origin of Flight Path - Outer Marker
Altitude, 1328' above ground

Figure 6. Diagram of experimental plan and flight path of simulator Experiment 3.

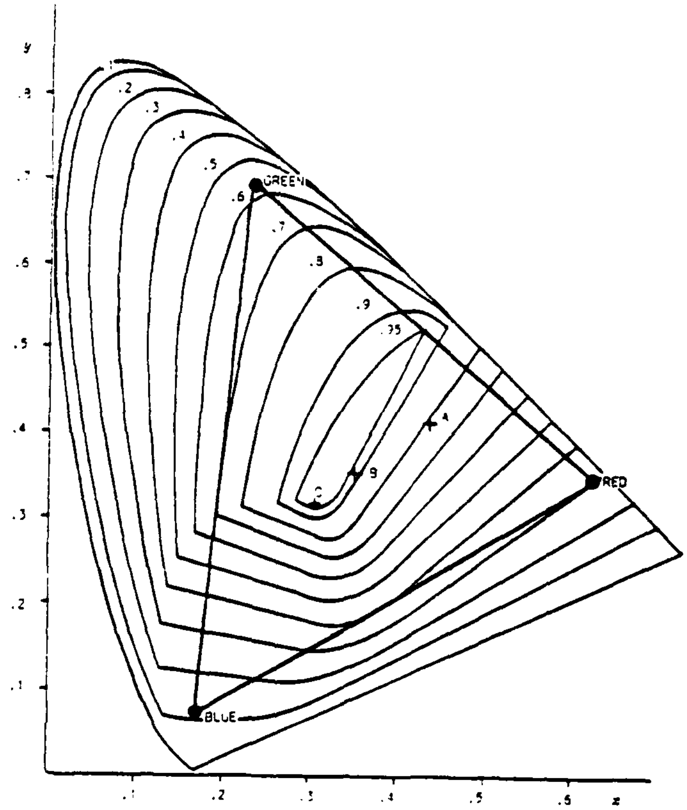


Figure 7. Topography of perceived brightness superimposed on standard chromaticity chart. The triangle encloses the area of colors and brightness levels reproduced with a tricolor phosphor tube.

for the pilots. The variation may be due to the specific adjustments of the maintenance people in balancing the color setting for night and day scenes. This proves to be a difficult task as the three primaries must be mixed to give an acceptable black background for night scenes and an acceptable white for the day scenes.

The Munsell Book of Color was chosen as a standard. This book contains over 1200 individually removable chips. In our cabinet edition these were glossy surface samples, arranged in two loose leaf volumes. The chips are a systematic series of sequences that are found in equal visual intervals of color regardless of the variations required in the physical stimulus to produce them. Colorimetric specifications are known for all of the chips in the Munsell Book of Color for illumination by daylight, either natural or artificial. The Munsell color system was developed from judgments of equal hue, value (brightness), and chroma (saturation) and includes 40 equally spaced hues on a scale from zero to 100, a value scale of 10 equally spaced brightness intervals and absolute chroma scales (number of steps depending upon hue and value) representing equal differences in saturation. Figure 8 illustrates Dorothy Nickerson's diagram of how the Munsell color system works. On the left is the dimensionalization, bottom to top, of a luminance intensity. Around the color circles are the specific hues and off to the right or dimension away from the center pole is the dimension of chroma. On the right hand side of this illustration is a replication of a page from the book representing a value for yellow, 5.0 and on the abscissa from left to right, an increasing value of chroma, and, from bottom to top, an increasing brightness.

A portable, battery-powered illuminance standard source was built which reflected color corrected light from a small integrating sphere off the individual colored chips. The device allowed one chip at a time to be viewed adjacent to a similar sized (visual angle) CRT generated virtual image. The illuminance from the integrating sphere fell on the Munsell Chip at 45° from the line of sight and a small 1/8" vertical light trap avoided any spill light on the beam splitter or CRT and also served as a gray septum between the two colors to be matched.

All color matching was done on the third visual channel of the 747. This was the forward scene of the 30°x 40° field of view that was used by the Air Force pilots throughout the experiment. All matching was done with a dark cab, observer in the captain's seat and a verbal relay to the data base specialist handling the Compuscene input typewriters.

By trial and error, the values for the three primaries; red, green, and blue were selected visually to match the standard desired for each of the color conditions. For the red surround a hue of 10R, a chroma of 16 and a value of 5 was chosen as the basic color. This was used as the single color surrounding the runway in the simple scene. For the complex scene with the red surround, this hue was also used as the basic color, but each object or pattern that was perceptually different were of the same hue but different saturations or chroma units of 12, 10, 8 and 6. This means that we held the hue constant and changed the saturation by adding white. This can be diagrammed as in Figure 9.

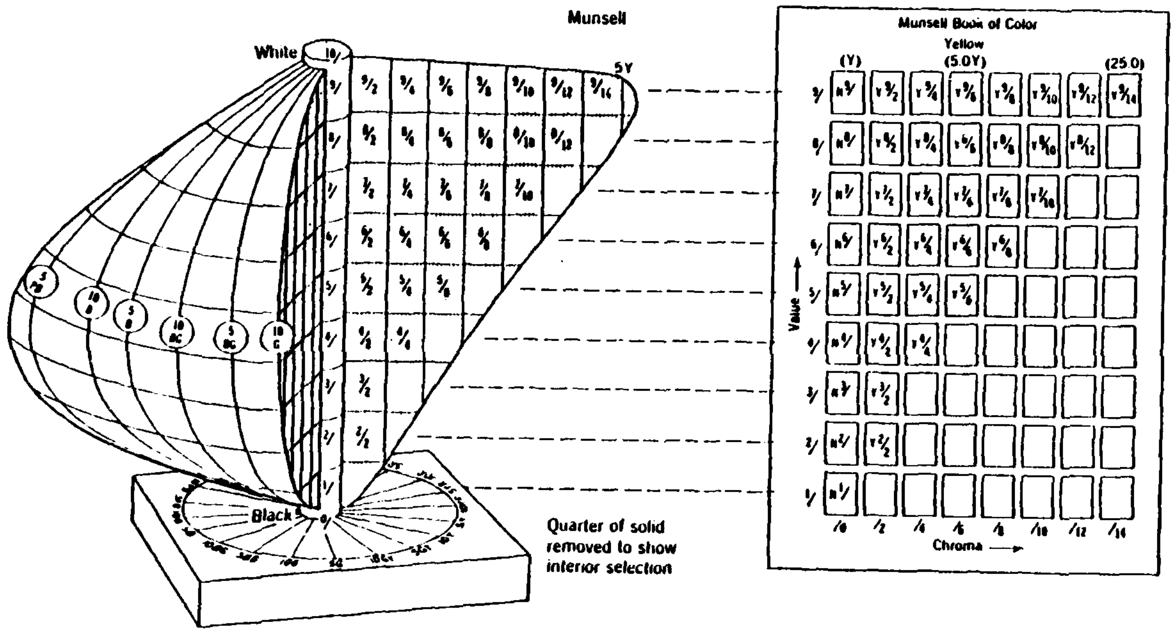


Figure 8. Munsell color system. A system of specifying object-colors on scales of hue, value, and chroma.

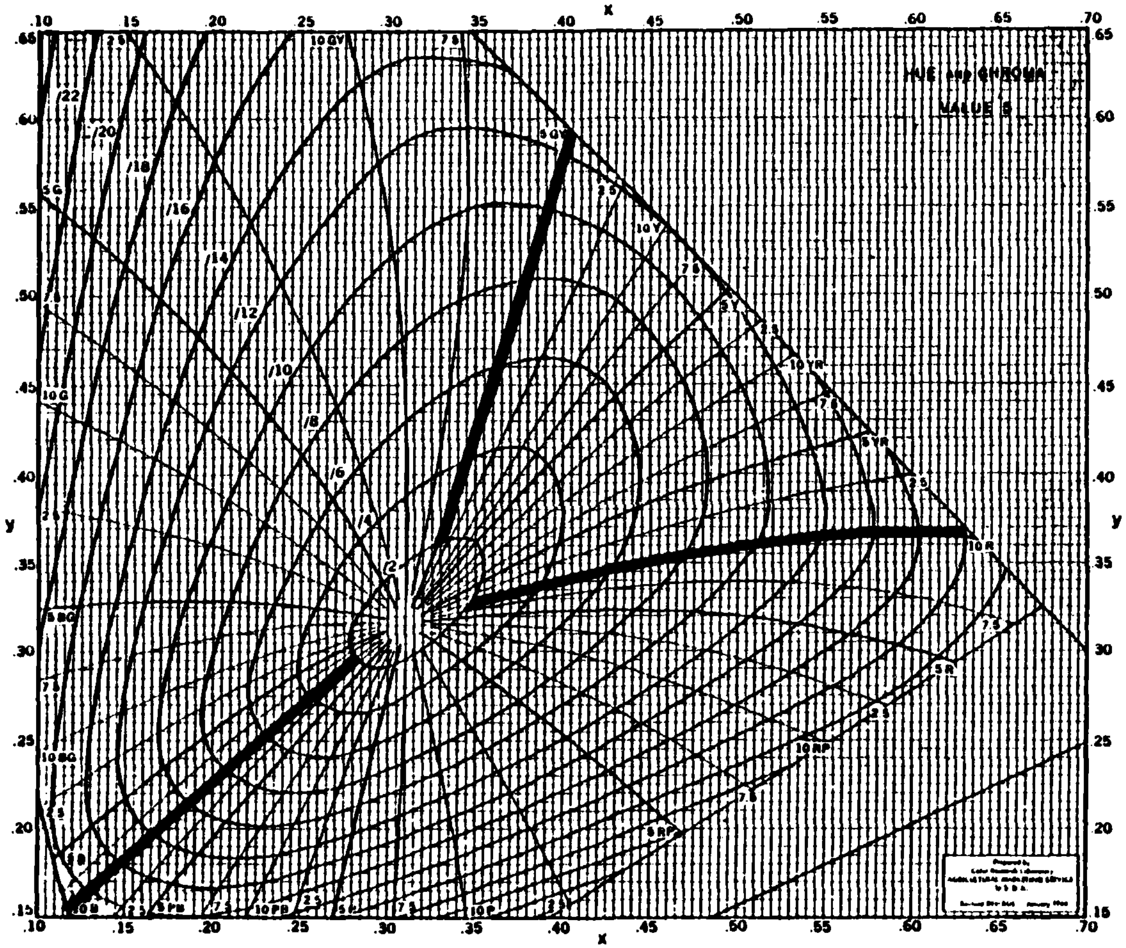


Figure 9. 1931 CIE chromaticity diagram showing loci of constant hue and constant chroma at value 5/ of Munsell renotation system with special designation of the hue and chroma used in experiments 2 and 3 (redrawn from Dorothy Nickerson).

Figure 9 is a representation of the 1931 CIE chromaticity diagram for the valu: of five, on the right the 10R hue and chroma the Munsell renotation system. On the left of this diagram is the 10B hue, which at a chroma of 10 and a value of 5 which was the basic color for the blue surround. The four additional saturations for the complex scene were chromas of 8, 6, 4 and 2, which were also along the desaturated low side of this diagram. The single point designated along the 5Y hue is the color of the sandy soil that was used in Experiment 2.

The basic and desaturated hues were all matched at a common luminance intensity of .9 foot lamberts. The runway color was selected to have the same hue as the blue surround 10B, and a chroma of 1 and a value of 2 as illustrated in Figure 9. This combination of chroma and value resulted in a measured luminance intensity of 0.3 ftL.

It may be of some assistance to the reader to refer to Figure 10 which illustrates the subjective dimensions of color as used in the Munsell Book of Color. Considering the circle, the outside perimeter of the circle as the most saturated color, that is the purest color of a particular wavelength, the dimension that we varied in terms of the five steps is moving from the perimeter of the circle toward the center , the area designated as grey. Then, to match our luminance intensities, we moved up the column toward the white and we chose the three points on the perimeter of that circle, the blue, red, and yellow to be used in each of the studies.

In Experiment 3, we were comparing pilot performance with the surround hues of red versus blue. The runway color was chosen to have the same dominant wavelength as the blue surround. In making the blue/ black appearance we effectively moved down the vertical column toward the bottom of the center column.

Special data bases were prepared for these experimental investigations. The selected colors were assigned to the simple and complex scenes according to the values determined in this comparative standardization. Each combination of surround color scene complexity and starting position had a particular reference number which could be selected by the experimenters. Each had a prearranged distribution of chroma and values for specified objects in the complex scene or the one hue, chroma and value for the simple scene runway surround.

Procedure in 747 Approaches

At the beginning of the flights in Experiment 3, the pilots had completed the 16 trials of Experiment 1 and 16 trials of Experiment 2 and began experiment 3 after a rest of about 10 minutes. The instructions given the pilots were very similar to those of Experiment 2. They were: The aircraft will be frozen at the outer marker 4.7 miles from touchdown at an altitude of 1330 feet above ground level. You are asked to make a straight in letdown to the 1000 ft. distance from the leading edge of the runway. Attempt to make as soft a touchdown as possible at this 1000 ft. reference as though you were carrying a load of passengers. The flap settings and other aircraft characteristics

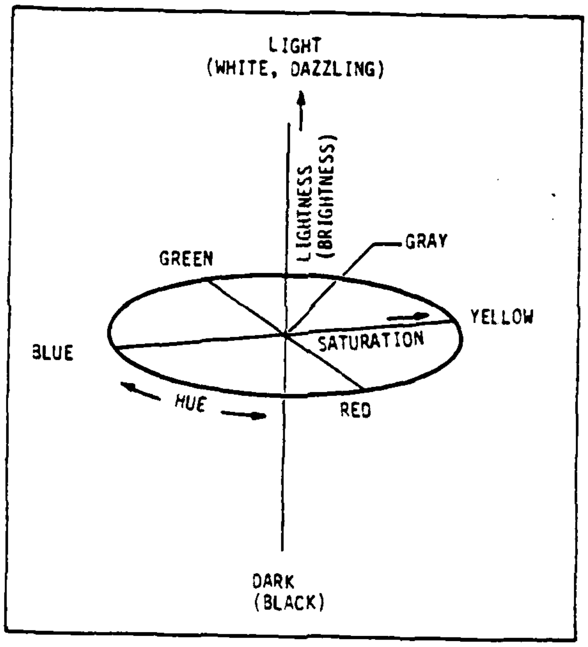


Figure 10. Subjective dimensions of color.

are the same as in the prior experiments. Again you will be making 16 approaches, 4 each under 4 separate conditions. In this experiment we are investigating the influence of the color of the runway surround. You will have two different colored surroundings of the blue/black runway, red or blue. Each color will be present for a simple scene and a complex scene. Which order of these four combinations you will receive first, second, third or fourth has been present to complete a balanced order across the pilots. The aircraft will be released to you with position and altitude frozen. When you have the aircraft stabilized to your satisfaction in pitch, roll and heading, advise the experimenter. He will tell you when he removes the altitude freeze and then the position freeze by saying "you're flying." Continue the approach through touchdown as in the just preceding experiments. The radar altimeter, barometric altimeter, and vertical speed indicator will again be covered. The ILS azimuth and glideslope are disabled and therefore these are strictly visual approaches or "non-precision" approaches. Any questions? If not we will proceed.

The Air Force pilot was again flying from the left forward seat of the 747. In all of these approaches he had a 114° field of view. The independent variables were the color of the surround and the complexity of the scene, each at two levels. We were operating with either two or three experimenters within the cab. One experimenter rode as a safety pilot in the right forward seat and monitored flight instruments for a general assessment of performance. One experimenter operated the flight instructor's station at the left rear of the cab and the third experimenter kept the protocol and monitored switches and identifying system for the electromagnetic tape records. The motion base was active during all trials.

In all, 18 pilots flew in Experiment 3, and 15 were selected to form the three groups of five pilots each, the groups representing 50, 0 and +50 arc seconds of chromostereopsis. Initially it had been planned to fly just 16 pilots, however some loss in the recording of Experiments 1 and 2 required running of two additional pilots in Experiment 3. One of the three additional alternatives was eventually not useful as an unusually short landing excluded the availability of a number of the dependent measures.

As soon as any one trial was complete the simulator was reset at the outer marker and at altitude, and preparations were begun for the second trial. No information was fed back to the pilot about his performance on any of the previous trials during the actual collection of data.

The experimenter in the right front seat kept a record of errata and a protocol of comments from the pilots. Such records were useful in the later identification of recordings. This experimenter also served in the role of safety pilot, he never acted in this capacity as all runs were within the structural limits of the simulator. He did keep a running record from reading his instruments on such things as altitude over the middle marker, altitude over runway threshold, number of seconds from threshold to touchdown, just in case these might be helpful in identifying records if the identification code should be missing or scrambled.

Analysis

The electromagnetic records used in experiment 3 contained the 37 dependent measures described earlier. Analysis were not done on each of these as time and economics did not permit us the luxury of pursuing our academic interest in looking at the total battery. Those that were selected were based on:

a) Those dependent measures that had proved useful in prior experiments that used the task of a straight-in visually dependent approach.

b) Theoretical and practical considerations of what pilots might alter in the flight regime if they found their estimates of height and distance to be in error.

c) The probability that recognition of errors in height and distance would occur when new sources of visual cues became available.

The considerations under (c) led us to choosi four distances from the zero reference point along the approach path. The data of Harvey and Michon (1976) would indicate that the threshold for motion would begin to occur at 10,300 ft. distance for the 300 ft. wide runway with an approach speed of 250 ft. per second or 148 knots. We therefore chose to make two analyses at greater distances (15,190 and 12,150 ft.) and two at lesser distances (6,076 and 3,038) than the distance for the threshold of motion. The relationship of these analyses to the total flight path are illustrated in Figure 11.

At each of the four longitudinally dependent loci five separate analyses were completed. The dependent variables for each of these were altitude, glideslope deviation, vertical speed, pitch angle and pitch angle rate. Table 59 illustrates which of these analysis showed some statistically significant differences as well as those that showed no significance.

Two sets of touchdown analyses were used. One set represented the 0.450 millisecond sampling just before touchdown and included seven separate analyses. The second set of touchdown analyses is designated as adjusted analyses and included two ANOVAS. The adjustment was toward maximizing the accuracy of assessment of the true longitudinal position of touchdown. The 747 has two sets of main landing gear and the altitude sensor is just aft of the lead main gear. The computer controlled setting of the "touchdown flag" may vary as to longitudinal position on the runway as a function of descent rate, true air speed, pitch angle and the magnitude of gear compression that defines touchdown. This adjusted analysis has a correction for: (a) the pitch angle effect on altitude at touchdown, (b) the vertical velocity effect on the speed with which tne 2.5 ft. of gear compression occurs after the aft gear contacts the runway, (c) the reversal of the computer reference sign to make the LONG measure a negative value relative to landing short of the 1000 ft. mark and (d) a correction of 840 feet to shift the electronic zero reference to the instructional reference of 1000 ft.

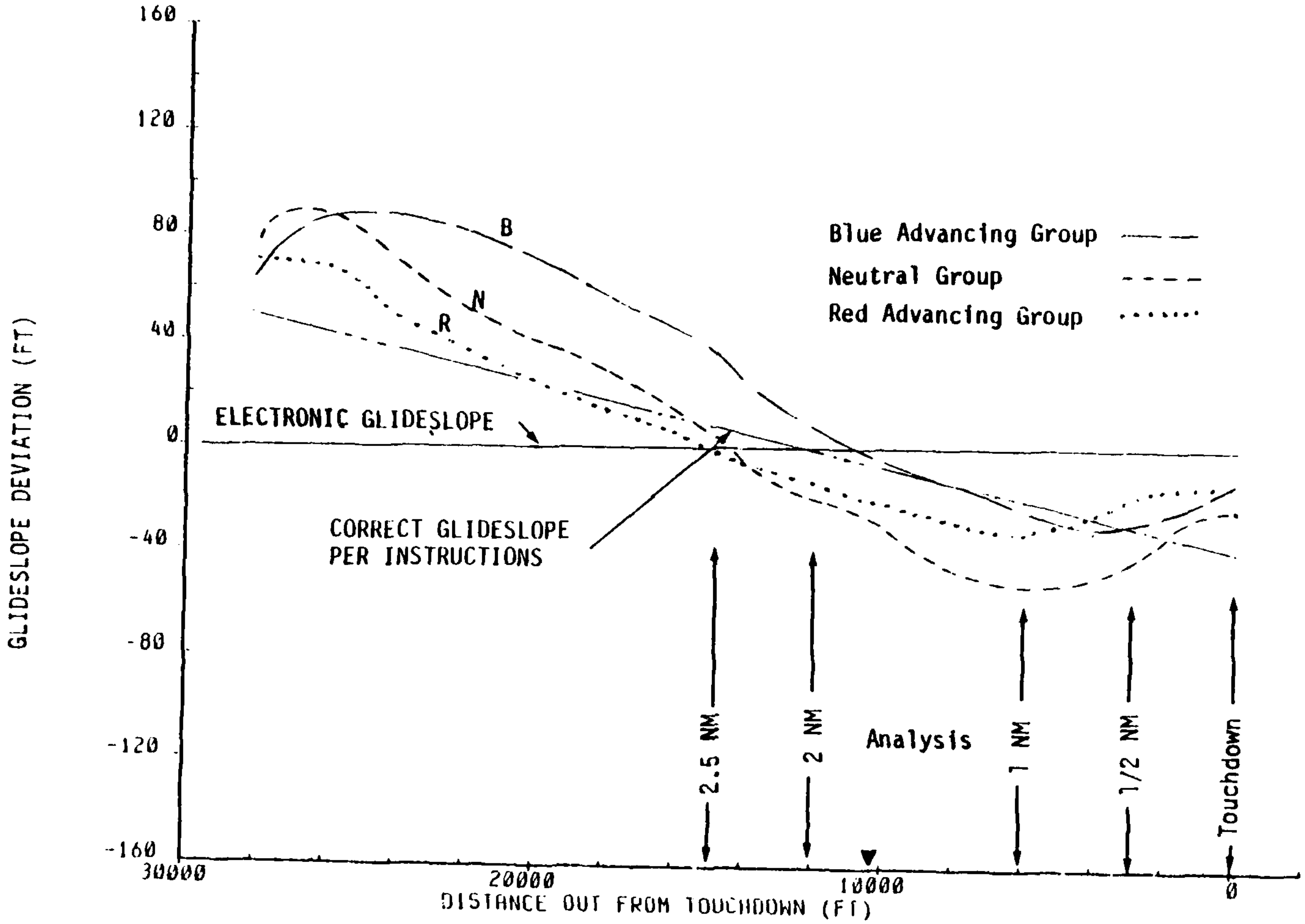


Figure 11. Average glideslope deviation for each chromostereopsis group across all conditions.

Table 59. Significant main effects and interactions for dependent variables submitted to analysis in Experiment #3.

Code	Definition	Long = 15,190' (2.5 NM out)	Long = 12,150' (2 NM out)	Long = 6,076' (1 NM out)	Long = 3,038' (0.5 NM out)	Touchdown - 1	Touchdown Adj.
H	CG Altitude (uncorrected) (Ft)	T,TS	T	N.S.	N.S.	N/A	N/A
GSPE	Glideslope deviation (Ft)	T,TS	T				
GSCA1	Calculated G.S. Deviation (Ft)						C,CG
LONG	Longitudinal distance out from 1840 mark (Ft)	N/A	N/A	N/A	N/A	C,CG	N/A
LONGAV	Distance from visual (1000') mark (signs reversed) (Ft)	N/A	N/A	N/A	N/A	N/A	C,CG
LATD	Lateral displacement from runway centerline (Ft)					N.S	
ROC	Rate of climb (Ft/sec)	N.S.	CS	TSG TS	TS	TSCG	
VTRU	True airspeed (Ft/sec)					N.S.	
THTA	Pitch angle (Degrees)	N.S.	T	TS,SG	TS,CG SG	N.S.	
THE+	Pitch angle rate (Deg/sec)	TC	TCG, TG,TS	CS CSG	N.S.	N.S.	
AOA	Angle of attack (Degrees)					N.S.	

Each analysis was printed out as the arithmetic mean and standard deviation of the main effects and interactions among these main effects. The ANOVA tables provided for each of these analysis, the source of variance, the sums of squares , the degrees of freedom, the mean squares for each enumerator and denominator of the F ratios. The F ratios and the corresponding values are listed. Each significant p value is marked with one asterisk for the .05 level and two for the .01. Each of the 18 ANOVAS completed for this experiment will be found in Appendix D.

The illustrations were either computer drawn or constructed by hand from the computer readouts. A number of plots of altitude as a function of longitudinal distance and glideslope deviation as a function of longitudinal distance were used to visualize these data before analyses were undertaken.

RESULTS AND DISCUSSION - EXPERIMENT #3

The main effects of Experiment 3 that were of special interest and unique to this experiment were the color of the runway surrounds, at two levels, and chromostereopsis groups, at three levels.

The original hypothesis was that there would be little difference in the performance of the three chromostereopsis groups, when the blue/black runway was surrounded by a blue surface. The theory was that the perception of hues with the same or similar dominant wavelengths would be seen as occupying similar spatial positions within the range that could be attributed to luminance differences.

In contrast the hypothesis held that with scenes wherein the hue of the runway was of contrasting dominant wavelengths to the hue of the surround, the three groups would perform differently in flying the aircraft. Further, that the blue advancing group would perceive the blue/black runway as being above the red surround. At a distance the predominantly red scene would appear further away from their aircraft, particularly with the simple scene.

The blue advancing group (BA) would initially remain higher, descend less rapidly until reaching 10,000 ft. from the runway, and afterwards, would maintain a slower descent rate, land shorter, and touchdown less hard than the other groups.

The neutral group (N) would have little, if any, difference in the responses to the color of the surround.

The red advancing group (RA) would see the blue/black macadam runway as below the surrounding red surface when the aircraft was near the runway. At a distance the scene would appear nearer their aircraft, particularly with the simple scene. The red advancing group would [illegible] remain lower, descent less rapidly, would possibly undershoot [illegible] more until inside the 10,000 ft. distance, would make a greater correction in altitude. The RA group would land longer and harder, having been too high in the final phases of the

In Figure 11 (see page 63) is represented the glideslope deviation in feet against distance from touchdown (also in feet). The three groups are here plotted as the average across all conditions. The reader will note that many of the hypotheses that have been stated above seem to be supported by these means.

In the same figure are depictions of an electronic glideslope simulator computer reference as well as a second glideslope that is labeled "correct per the instructions." The electronic glideslope is that reference that the analytical computer used to evaluate glideslope deviation (GSPE). The origin of the electronic glideslope is 1840 ft. down the runway and represents a 2.5° glideslope and at 4.7 nautical miles crosses the outer marker at an altitude of 1330 ft. AGL. The electronic glideslope in this graph is represented as the zero point on the ordinate and traverses all distances as a horizontal line. The second glideslope, identified as the correct glideslope per instructions, is the path that should have been followed by the pilots if they perfectly adhered to our verbal instructions. They were asked to leave the beginning altitude of 1330 ft. above ground level and make a straight-in descent to a point 1000 ft. from the front edge of the runway. The path these instructions describes is a 2.7° glideslope originating at 1000 ft. past the runway's leading edge.

Relationship Between the Analysis of Variance and the Total Descent Path

The basis for our selection of where to conduct analysis rested in part on where the pilot would begin to have the additional cue of motion perception. In the simple scene the only pattern visible was the runway. The additional motion cues that would first become available would be the separation of the right and left edges of the runway as the pattern expanded. The 300 ft. wide pattern would appear to dynamically widen 50 percent of the time as the aircraft passed through 1.4 nautical miles, or 8506 ft. Since the zero reference in this simulation was at 1840 ft. from the threshold, this just perceivable motion threshold point, would occur at 10,346 ft. on our computed distance scale. Here, it will be recalled, from the discussion under "Method" that we chose four distances out from the runway as sites for the ANOVAS, two beyond the motion threshold point and two inside this value. Again referring to Figure 11, the relative location of these analyses are shown to this threshold of expansion of the runway and to the total length of the approach. The initial choice of not having an analysis between 28,000 and 15,000 ft. was that this area would reflect the beginnings of the influences of the independent variables and that the first analysis at the 1500 ft. level would show its end results. However, reference to the Figure 11 indicates that it might have been the better choice to have included an ANOVA at a distance of 2200 ft. to determine if the differences between groups as to altitude and glideslope deviation were statistically significant. The discussion of the results will follow the pattern of discussing one dependent measure at a time.

Altitude

The first analysis conducted at 15,190 ft. or 2.5 nautical miles out does reflect a significant altitude difference, but only for trials and then the interaction of trials by scene complexity.

Table 60. Altitude as a function of trials at 2.5 nautical miles distance.

Trials	1	2	3	4
Mean	658.422	702.570	683.161	664.345
S.D.	99.955	93.374	114.088	82.814

The theoretical altitude at this distance was 676.7 ft. The average initial trial was below this value. The second and third trials were above and the final trial again low. The shape of this distribution is primarily contributed by the pilot's performance against the simple scene. This is shown by the means in the trial by scene complexity interaction shown in the following Table.

Table 61. Altitude as a function of trials by scene complexity interaction at 2.5 nautical miles distance.

Trials	1	2	3	4	
Mean	642.074	724.664	697.648	674.153	Simple
S.D.	106.617	104.563	121.535	69.409	
Mean	674.770	680.475	668.674	654.537	Complex
S.D.	91.687	76.122	106.189	94.531	

The ANOVA at 2 NM for altitude also showed trials as a main effect to be significant. However the means showed no trend different from that discussed for the 2.5 NM analysis.

The analysis at 1 NM and also at 1/2 NM showed that altitude was not a significant variable for any of the dependent variables nor for their interactions. This result was not supportive of the hypothesis as the expectancy was that the altitude would differ as a function of chromostereopsis groups interacting with the color of surround and scene complexity. There does exist a mean difference in altitude between the blue advancing and red advancing groups at the distance of these two analyses. The magnitude is small and the values invert between the two analyses; that is the A group is at a higher altitude at 1 NM and at a lower altitude at the half nautical mile. The N group is lower than both the RA and BA groups at both distances. However, the large variances between trials as illustrated in Figure 12 undoubtedly contribute to the lack of significance between the mean differences. It is surmised that at these distances the relative motion cues of the expanding width of the runway may be such an effective cue that it becomes the dominant source of information. If this is the case it may mask the effects of the other variables under investigation.

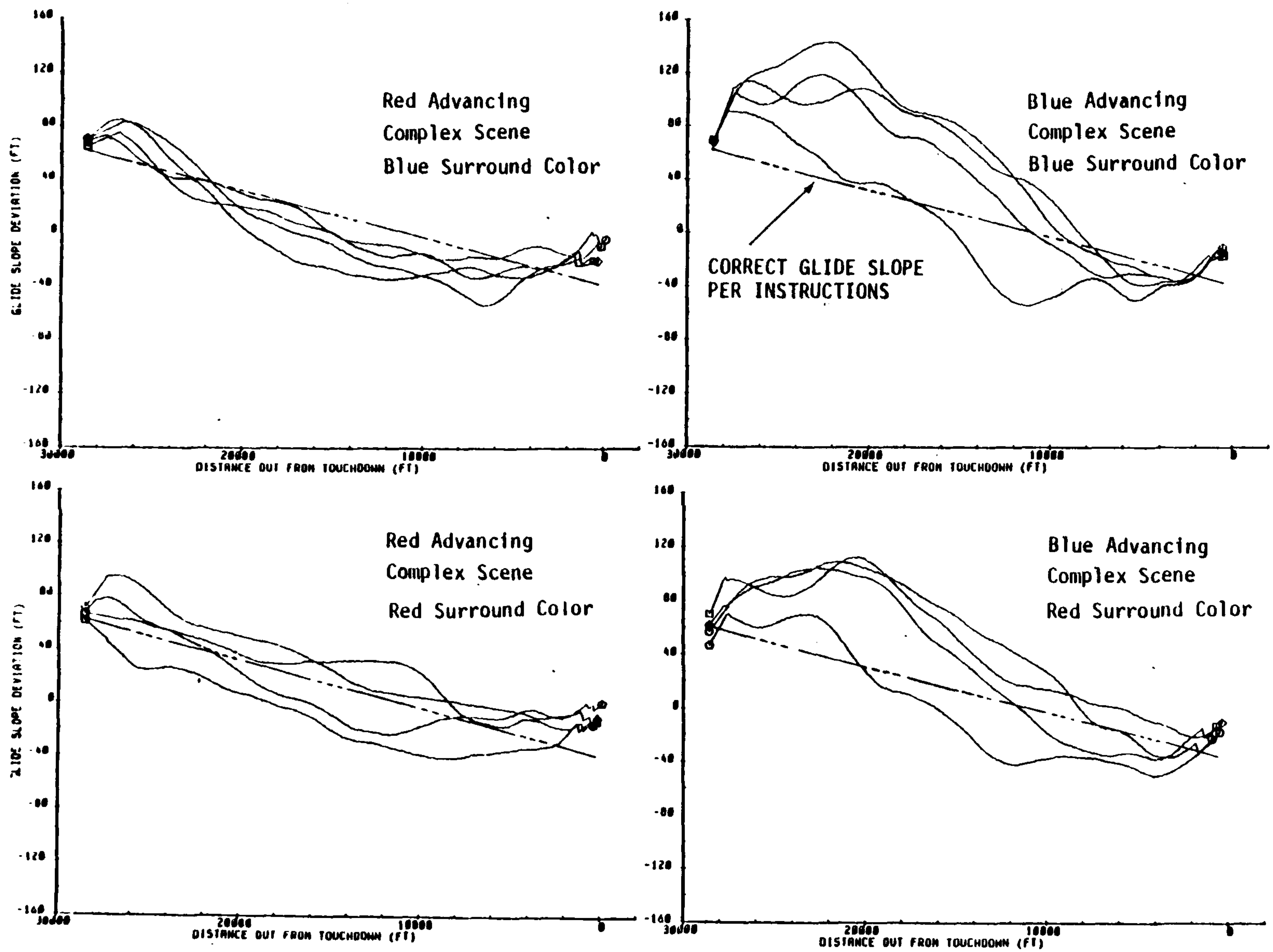


Figure 12. Glideslope deviation as a function of trials x scene complexity x color of surround x chromostereoscopic grouping of pilots.

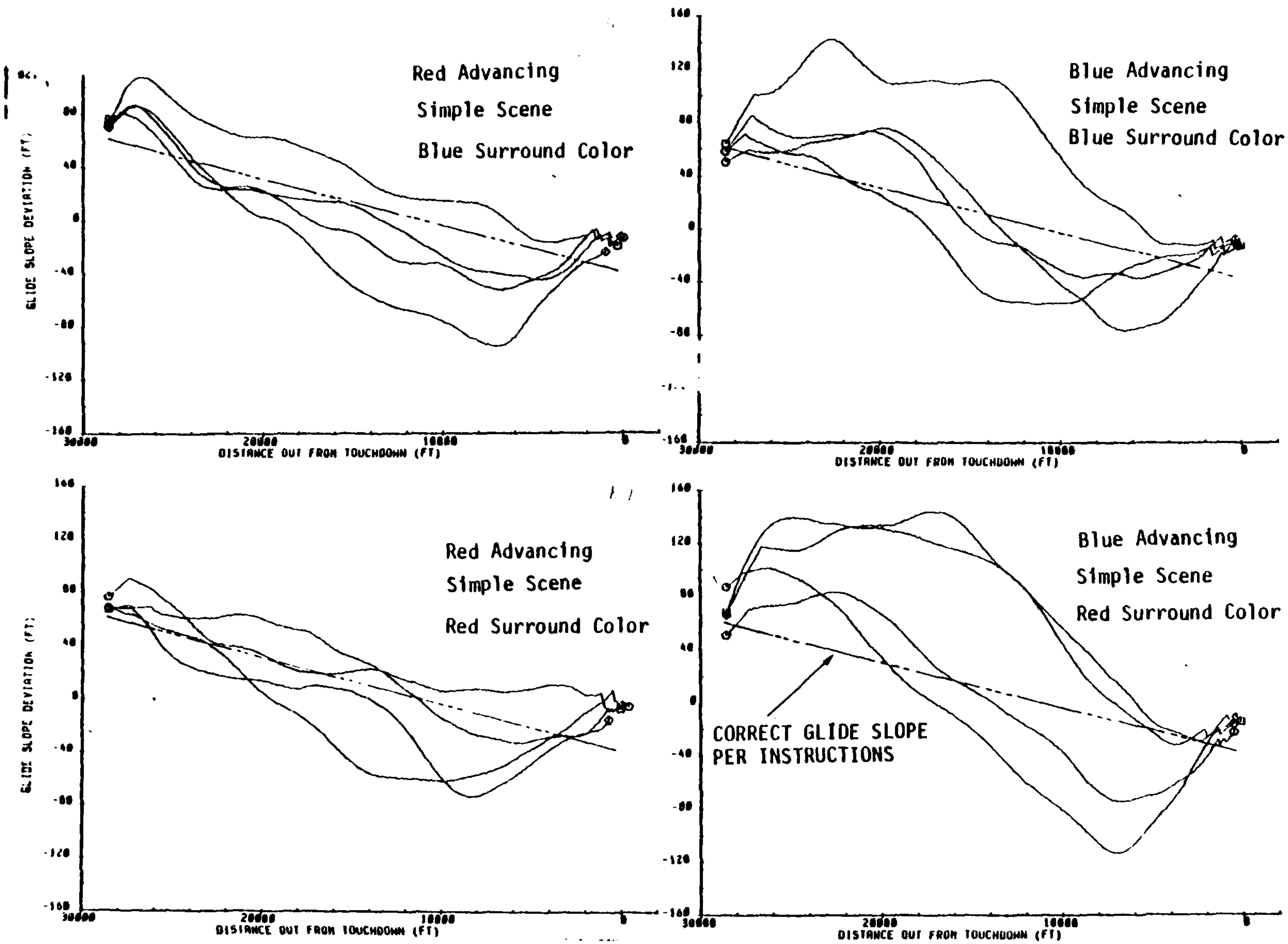


Figure 12 (continued). Glideslope deviation as a function of trials x scene complexity x color of surround x chromostereoscopic grouping of pilots.

Altitude as a dependent measure was not included in either of the touchdown analyses. By definition the altitude should have been invariant at touchdown, in actuality, the aircraft reference of zero altitude which is nominally about 16.5 ft. above the runway. At touchdown it does vary as a function of the amount of depression of the oleos, the pitch angle of the airplane, and the vertical velocity at time of touchdown. However these variations are not part of this investigation.

Glideslope Deviation

Glideslope deviation is not independent of altitude and, as expected, the same pattern of significant differences among the means was found for each analysis. At the distance of 2 NM trials as a main effect and trials by scene complexity interaction were significant as shown in the following two tables.

Table 62. Glideslope deviation for the four trials at the distance of 2 nautical miles.

Trials	1	2	3	4
Mean	-1.939	42.289	22.914	3.837
S.D.	99.914	93.400	114.191	82.670

Table 63. Glideslope deviation for trials x scene complexity interaction at the distance of 2 nautical miles.

Trials	1	2	3	4	
Mean	-18.200	64.396	37.326	13.727	
S.D.	106.630	104.586	121.447	69.103	Simple
Mean	14.322	20.182	8.502	-6.053	
S.D.	91.612	76.149	106.535	94.482	Complex

The comments developed earlier for altitude also pertain to glideslope deviation at 2 NM. The analysis at 1 NM indicated that the trial means were significantly different. The means showed an average undershoot on the first trial followed by overshooting on trials 2 and 3 and returning to an undershoot on trial 4. The values show a very small deviation from the glideslope averaging 5.1 ft. over trials. This average trial variation is just under one percent of the glideslope altitude at this distance.

Table 64. Glideslope deviation as a function of trials at the 1 nautical mile distance.

Trials	1	2	3	4
Mean	-26.31	13.91	6.73	-19.80
S.D.	100.75	89.40	114.90	98.29

The standard deviation was for the interactions of color or runway surround x scene complexity x chromostereoscopic groups. Distances of 2.5, 2 and 1 NM showed an interesting trend. For all chromostereoscopic groups, the smallest variances were found for the complex scene with the red surround color. The simplest explanation for this may rest with the apparent chromatic contrast. It was observed that this was possibly greater for the red surround. It was noted that although the five steps of saturation of the 10-R hue, all appeared as red when they were displayed as a single color against a grey field. They appeared to be of other hues when mixed in the complex scene. The scene appeared to be composed of three reds, an orange and a yellow. This multihue shift was much less observable among the five saturations of blue.

A secondary observation was that the smallest variances were associated with the red advancing group when flying to the complex scene with the red surround. An ANOVA was run on the standard deviations squared and transformed to natural logs. The main effects were: scene complexity, surround color, chromostereopsis groups, pilots and distance. That is the color x complexity x group interactions were the source of these data across the distances of 2.5, 2.0 and 1.0 NM. The trend was supported by the analysis but only the dimension of distance proved significant.

Figure 13 is constructed of four plots of distance by glideslope deviation. Each graph includes a plot of the electronic glideslope and the correct glideslope per instructions, using the 1000 ft. mark as a reference. Each graph has a plot of glideslope deviation for the blue advancing, neutral, and red advancing groups. The computer plotted these backward from the average touchdown point. Plot A illustrates the performance of these three chromostereopsis groups of five pilots each as an average deviation against the simple scene and blue runway surround. Plot B deals with the same simple scene but with the red runway surround. Plots C and D refer to the complex scene, blue surround and red surround respectively.

In A through D plots the RA group remains generally lower than the BA group until after the instruction glideslope (IGS) crosses over the electronic glideslope. The BA group remains generally nearer the IGS when the surround color is blue. The RA group remains generally closer to the IGS when the surround color is red.

To obtain a metric that would reflect these observations, a vertical line from each average descent path as it crossed over the electronic glideslope was dropped to the abscissa. From the abscissa's intersect, we read "crossover value" and constructed the Table 65.

On the left of this table we have listed the crossover values in descending order and arbitrarily separated these at one half the total approach distance. It will be noted that this arbitrary division into halves includes, in the most distant half, all the red advancing groups against complex and simple scenes, and the two neutral groups with the complex scenes. The half of the crossovers that are nearer the touchdown point include all of the blue advancing groups and the two neutral groups with the simple scenes. The means of the two halves are statistically different $t = 5.8$, $p = <.01$.

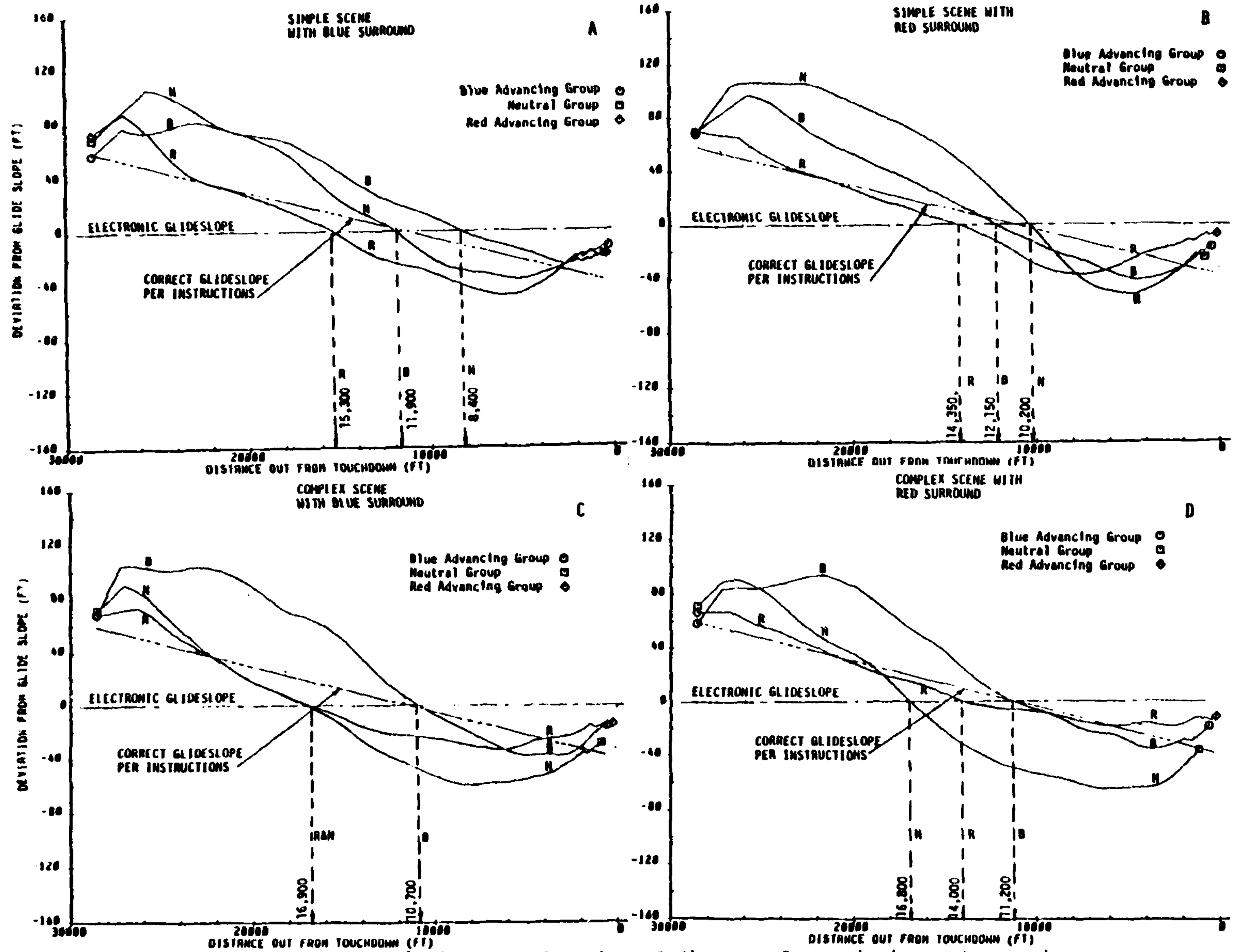


Figure 13. Glideslope deviation as a function of distance for each chromostereopsis group.

Table 65. Distance from 1000' mark where cross-over of glide slope occurs as a function of chromostereoscopic group, surround color and scene complexity.

Cross-over Distance (feet)	Area Above Glide Slope	Chromostereoscopic Group		Runway Surround Color	Scene Complexity
16,900	.0166	Red Advancing	(RA)	Blue	Complex
16,900	.0189	Neutral	(N)	Blue	Complex
16,800	.0248		(N)	Red	Complex
15,300	.0189		(RA)	Blue	Simple
14,350	.0176		(RA)	Red	Simple
14,000	.0186		(RA)	Red	Complex
12,150	.0315	Blue Advancing	(BA)	Red	Simple
11,900	.0358		(N)	Blue	Simple
11,200	.0380		(BA)	Red	Complex
10,700	.0445		(BA)	Blue	Complex
10,200	.0473		(N)	Red	Simple
8,400	.0377		(BA)	Blue	Simple

Distant crossovers = All red advancing groups; 2 neutral groups with complex scenes.

Near crossovers = All blue advancing groups; 2 neutral groups with simple scenes.

(both with an equal division of peripheral field color)

In an attempt to determine if another metric would also reflect the same division, we dropped a perpendicular from the origin of each of the flight paths to the electronic glideslope, thereby enclosing an area. Then, with a Planimeter, we measured the size of this area on the graphic reproduction and ranked these in the order of increasing area. This metric is inversely correlated with the crossover distance as would be expected, and the difference between the mean areas for the two halves (distant vs. near crossovers) is statistically significant using a two tailed t test without correlation ($t = 14.9$, $p = < .01$).

These data are indicative that the blue advancing group generally flies higher for the initial part of their approach. In addition, if they are approaching a red surround, they continue to be above the glideslope for a longer period of time and cross over nearer the runway. The red advancing group on the average fly nearer to the glideslope than the blue advancing group. The RA group, in addition, also fly lower when approaching a blue surround and both of these trends lead to a more distant crossover of the electronic glideslope. The neutral group is equally divided in that, against the complex scene, they fly differently to the two colors of the runway surrounds.

The trends that involve the interaction of the groups with the color of the surround are all consistent with the hypothesis developed in the introduction to this experiment.

Vertical Velocity

The analysis of vertical velocity at touchdown is to be seen in Appendix D and was a 4 x 2 x 2 x 5 x 3 ANOVA. The variables with these levels were in the same order: Trials, color of area surrounding the runway, scene complexity, pilots and chromostereopsis grouping.

To provide an orientation for the discussion of the above interaction a review of the main effects, though they are not significantly different, may be helpful as to orientation. Trials, which were four, varied from minus 6.02 to minus 6.82 feet per second at 0.450 milliseconds before touchdown. However, no systematic trend was evident.

Color of the area around the runway showed a slightly lower vertical velocity for red (-6.28) compared with blue (-6.44). The complex scene also lowered the vertical velocity (-6.15) compared with -6.57 for the simple scene. The three chromostereopsis groupings showed progressively less descent rate in the order of NC group (-6.83), BA group (-6.32) and RA group (-5.93).

The RA group had lowest vertical velocity for both red and blue colored surrounds and for simple and complex scenes. The RA group also had the lowest percent of vertical velocities that exceeded the design limits of the aircraft (10 ft./second). The RA group's percentage was 2.5 percent. The BA and NC groups both had 7.5 percent.

The relative superiority of the red advancing group for these aspects of vertical velocity at touchdown raises the question about

the matching of the groups. It will be recalled from an earlier discussion that although these groups are very closely matched as to chromostereopsis and relatively closely matched as to age, the number of hours of experience is in favor of the blue advancing group that has 3,432 as an average number of hours. The neutral group averaged 2,100 hours and the red advancing group 1,730. So if total flying hours were indicative of higher skill on the part of pilots, it would be opposite the effect observed with those data on vertical velocity. However, a regression analysis and a correlation study of the relationship between total number of hours and pilot performance in vertical velocity and touchdown was performed. The linear regression shows a decrease in vertical velocity as the number of hours of pilot experience increases, but due to the very large standard deviation among the 15 pilots as to the total number of hours, the coefficient of correlation, although negative is essentially zero. This correlation and regression does not eliminate the possibility that the red advancing group does contain five pilots of higher skill. However the direction of the statistic indicates that we would expect the higher performance on the blue advancing and neutral groups than on the red advancing group.

To gain our best understanding of the third order interaction we did multidimensional plots wherein vertical velocity was the ordinate and the two abscissas represented scene complexity and color of surround. In a separate graph for each chromostereopsis group, we drew a surface for each of the four successive trials. These graphs indicated that for the blue advancing group the red/simple dimension shows a decrease in vertical velocity between the first and fourth trial with the near replication of the velocities on trials 2 and 3. All other color complexity interactions are characterized by a high value on trial 1, a low value on trial 2 and 3 and a return to the high value on the 4th trial. The neutral group had a very different pattern of responses as a function of the four trials. Generally at each successive trial there was an improvement in the touchdown rate, except for the complex/red combination. In the complex/red combination, the first and second and fourth trials are relatively low. There is a systematic improvement from -8.4 to -4.6 ft/sec. in touchdown velocity for the complex/blue surround combination. However the neutral group has a higher touchdown rate than both of the other groupings.

The red advancing group differs from the other two in that from the first trials, which measured 6.4, 6.2, 6.0 and 5.8 ft/sec. of descent, the values indicate that for the first trials there is almost equal vertical velocity for each combination of the color of surround x the scene complexity. However, in each of the subsequent trials, there is a rotation around a particular axis, that is, a line drawn between the red/complex to the blue/simple. The rotation then could mean that the simple/red dimension could increase or decrease and the blue/complex could increase or decrease. The rotation doesn't take place until, on the third and fourth trials the peak descent rate all have moved to the blue color axis. That is, the red advancing group on their third and fourth trials have their high rates of descent rather than on the first or second trials

Examining the variances that were reported in this analysis of variance of the trials by color, by scene complexity, by chromostereop-

sis grouping interaction, one notices an interesting trend. For the red advancing group, flying to the simple scene, the standard deviation across the five pilots on all trials is larger for the red surround color than when flying to the blue/black macadam runway against a blue surround. The mean difference of this variance amounts to 6.05 but it does not meet the criterion for significance at the $<.05$ level when a t test with correlations is applied. It does exceed the $< .10$ and for some investigators, this would be indicative of a trend worth investigating. The difference may be contrasted with the same measure for the BA and NC groups which were .39 and .97 respectively.

This largest variance found in this ANOVA and its direction directly support the original hypotheses, that is, that the pilots with red advancing chromostereopsis, when faced with a runway surround color of wavelengths differing from the runway itself, would estimate their heights differently than they would if the blue/black macadam runway were surrounded with a like series of wavelengths.

The blue/black runway surrounded by a extensive field of blue would provide a minimum contrast in stereoscopic height and a lower variance among pilots in estimating height above the runway. The N group should show a minimum difference between the red and blue color surrounds and their variance in performance should be similar, as they were. The BA group would see the red surround color as further away than the runway and should have shown higher variance against this mixture of colors. This was not the case, as the BA group had very similar variances (difference = 0.38) when flying against either color surround.

Why the BA group differed from the RA group in variance in flying to the mixed color scene is a matter of conjecture. The explanation may rest with how one perceives the height of the runway relative to the surrounding surface. The RA group with the red color surround may perceive the blue/black runway as being below the surrounding plane, a very atypical situation, and one producing higher variance in vertical velocity. The BA group may, with the red surround, see the runway above the surrounding plane (a more typical condition to be found in operational flying) and therefore their experience transfers better to this experimental situation. With this better transfer, variability remains about the same as with the blue/black runway and blue surround color. There are no data that support or invalidate this hypothesis within this experimental investigation.

Vertical velocity at the four different distances shows some statistically significant changes. These are best understood with reference to the earlier Figure 11, which includes the average glideslope deviations as a function of distance for each of the three chromostereopsis groups.

The surround color and the scene complexity interacts significantly at the two nautical mile distance. At this distance the neutral group is descending at 13.07 ft/sec and the BA group is descending at 13.92 ft sec, both faster than the RA group which is descending at 12.36 ft/

sec. At the same groundspeed 11.3 ft/sec would be required to remain parallel to the glideslope. The crossover between the red surround/simple scene and the blue surround/complex scene having a higher descent rate than the red surround/complex scene and blue surround and simple scene is shown in the following Table.

Table 66. Vertical velocity as an interaction between color of surround and scene complexity

	Red Field	Blue Field	
Mean	-13.98	-12.66	
S.D.	3.10	3.25	Simple
Mean	-12.68	-13.16	
S.D.	2.53	2.67	Complex

Analyses of the individual letdown curves for each of the groups by the trials indicates that this crossover may be a function of just a correction for being higher in the first two instances and relatively lower on the latter two. The trials by scene complexity interaction, significant at this distance, indicates an earlier slowing of vertical velocity against a complex scene, while with the simple scene, the rates are fluctuating more among the trials and remain higher than the theoretical average. The trials x scene complexity x chromostereopsis group interaction is explained by the fact that the blue advancing and neutral groups are descending faster against the simple scene and the red advancing group is equal in the rates of descent on the complex scene. At the one half nautical mile distance, the average rate of descent is close to that of the theoretical, and the groups have slowed against both complexities to an overall average of about 10.7 ft/sec. At this distance the trial by scene complexity interaction shows that, against the simple scene, the first trial is slower. Then the rate is again increased on 2, 3 and 4. Against the complex scene there is a general shift of slowing on the subsequent trials to be significantly below the standard descent rate of 11.3. The neutral group is significantly below the standard descent rate of 11.3. It is the neutral group, at this instance, who are most rapidly decreasing their vertical velocity. Figure 11 will show that they are correcting for being underneath the glideslope at this point.

Pitch Angle

The analyses at two nautical miles shows a significant change in pitch as a function of trials. This appears to be an alternation between a steeper pitch on the first and third trials and lower pitch on the second and fourth. The explanation probably is that these pitch changes reflect a series of alternating adjustments to maintain the estimated glideslope angle.

Table 67. Pitch angle as a function of trials at distance of 2 nautical miles.

Trials	1	2	3	4
Means	2.52	1.97	2.34	2.11
S.D.	1.55	1.59	1.47	1.30

At the one nautical mile distance the analyses indicated two interactions as being statistically significant. They were trials by scene complexity and, second, scene complexity by chromostereopsis groups. The pitch as a function of trials have two different alternation patterns, one for the simple and one for the complex scene. The latter has the greater positive pitch indicating that the pilots are slowing the descent rate more against the complex scene.

Table 68. Pitch angle trial means for successive levels of scene complexity.

	1	2	3	4	
Mean	2.43	1.74	2.18	2.10	
S.D.	1.72	1.77	1.61	1.44	Simple
Mean	2.60	2.19	2.50	2.11	
S.D.	1.38	1.37	1.31	1.16	Complex

At the distance of one nautical mile the red advancing group and the neutral group have reached their maximum departure below the instructional glideslope and are slowing their descent rate. This seems to be the explanation for the interaction between the complexity of the scene and the different groups by chromostereopsis. The neutral group's deviation is largest and they have pitched the aircraft up the greatest amount to slow this descent. The red advancing group has pitched their aircraft higher particularlv against the simple scene to check their rate of descent. The blue advancing group have the least pitch angle and their position is the most proximal to the glideslope of all three groups.

Table 69. Pitch angle as a function of scene complexity and chromostereopsis groups.

	Simple	Complex	
Means	2.095	1.795	BA
S.D.	1.209	1.344	
Means	2.796	4.048	N
S.D.	2.207	1.488	
Means	3.344	3.050	RA
S.D.	1.343	1.167	

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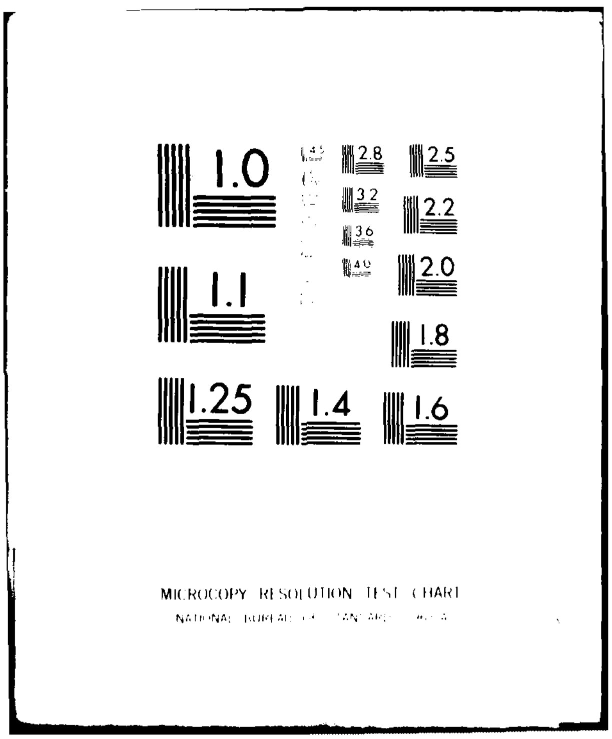
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MICROCOPY RESOLUTION TEST CHART

The analyses at one half nautical mile shows this continuing trend of the explanation for the different pitch angles as a function of the position of the aircraft relative to the instructional glideslope. There are three significant interactions found at this distance. The trials for successive levels of scene complexity maintain the alternating pattern for the simple scene. The trials flown toward the complex scene also show a slight alternating pattern, one that is exactly opposite in phase to that of the simple scene.

Table 70. Pitch angle as a function of trials by scene complexity at 1/2 nautical mile.

Trials	1	2	3	4	
Mean	3.145	2.629	3.296	2.813	
S.D.	1.850	1.849	1.742	1.902	Simple
Mean	2.997	3.455	3.194	3.611	
S.D.	1.472	1.932	1.538	1.527	Complex

At the same distance the color of the surround does influence the three chromostereopsis groups to perform differently as far as pitch angle is concerned. All groups are at this distance slowing the descent rate. The BA and N groups are lower against the red surround and are at this sampling point, pitched up more to slow their descent. The red advancing group is lower against the blue surround and is at the one half nautical mile distance, pitched up more than against the red surround.

Table 71. Pitch angle as a function of surround color and chromostereopsis grouping.

	Red Surround	Blue Surround	
Mean	2.509	2.191	
S.D.	1.224	1.116	BA
Mean	4.015	3.569	
S.D.	2.103	2.333	N
Mean	3.081	3.490	
S.D.	1.318	1.302	RA

The scene complexity also interacts with the chromostereoscopic grouping of pilots. The neutral group, at this distance, is the furthest below the glideslope than at any other time, and the pitch angle is the largest of these means for the approach against the complex scene. The red advancing group is next lowest of the three and it

also has the next highest pitch up. The BA group, prior to reaching this one half nautical mile position has started to slow its descent rate, and in this analysis, has the least pitch up of the three groups. For each of the groups then, the interaction is that the N group has the largest pitch up against red. The BA group has the largest pitch up with red and the red advancing group, the greatest pitch up against the blue surround color.

Table 72. Pitch angle as a function of scene complexity and chromostereopsis grouping at the 1/2 nautical mile distance.

	Simple	Complex	
Mean	2.365	2.335	
S.D.	1.276	1.080	BA
Mean	3.080	4.503	
S.D.	2.441	1.724	N
Mean	3.467	3.104	
S.D.	1.421	1.197	RA

The explanation of the order and magnitude of the pitch angle again rests with the deviation of the aircraft from the instructional glideslope. In each instance where the pitch angle is high, the glideslope deviation is proportionally large and its sign is such that the aircraft is below the glideslope. The chromostereopsis group's average response is slowing of the descent as if to correct the new perception of being relatively low. The neutral group was lowest against the complex scene and was pitched up 4.5° to slow the descent. At this sampling the BA group is proximal to the glideslope, having previously slowed the descent and now, at the one half nautical mile, had the least pitch angle against the complex scene.

Pitch Angle Rate

The pitch angle rate analysis at 2-1/2 NM indicates that trials are a significant variable. For the first three trials, the pitch angle rate for the complex scene is from 7 to 10 times less for the complex scene than for the simple scene. On the fourth trial, this ratio drops to be less than three and is opposite in sign for the two complexities.

Table 73. Pitch angle rate as a function of trials and scene complexity at the 2-1/2 nautical mile distance.

Trials	1	2	3	4	
Mean	0.040	0.047	0.027	-0.113	
S.D.	0.236	0.230	0.240	0.345	Red
Mean	0.006	-0.004	0.003	0.057	
S.D.	0.206	0.226	0.285	0.253	Blue

The interaction of trials by scene complexity is also significant at the 2 NM distance. The pitch angle rate, at this distance, for the complex scene, has increased until it is about one half that of the simple scene. The pattern of a negative pitch angle on trials 1 and 4, and positive on trials 2 and 3, for the complex scene, is almost a mirror image of the pattern by trials found for the simple scene.

Table 74. Pitch angle rate as a function of trials and scene complexity at the 2 nautical mile distance.

Trials	1	2	3	4	
Mean	0.08	-0.11	-0.11	-0.02	
S.D.	0.37	0.36	0.31	0.19	Simple
Mean	-0.09	0.06	0.02	-0.01	
S.D.	0.26	0.28	0.31	0.32	Complex

An interaction between trials and chromostereoscopic groups also exist as a statistically significant difference. It may not be of any practical significance. The largest value contained within the body of the table is .13 of a degree per second. That would mean that a 1 degree adjustment in pitch angle would take 7.7 seconds. Therefore these interactions are among the slow adjustments made in maintaining a particular descent rate.

A second order interaction among trials, color of runway surround and chromostereoscopic groups is statistically significant. Among the trials, the BA group has a very small range of pitch angle rates amounting to 0.15° per second when flying against the red scene. A larger range of 0.45° per second against the blue scene is shown for the same group. The range of difference in pitch angle rates for the red advancing group is similar, 0.10° for flights against the red scenes and 0.43° against the blue scene. The neutral group has a range of only .2° per second against the red scene, and .3° per second against the blue scene. Therefore, for all groups, the larger range of pitch angle rates is found against the blue scene color. The largest absolute rate is found for the neutral group versus the blue scene.

In terms of the mean glideslope deviation, the two mile distant analysis samples fairly steady states of descent for the RA and BA groups. The N group was continuing to change the pitch and slow their descent. However half a nautical mile further in, this group initiated an increased rate of descent only to check this just before the next analysis at the distance of 1 NM. The 1 NM analysis shows a significant interaction between the surround color and the complexity of the scene. At this distance the pitch angle rate of change is decreased against the red field when the more complex scene is present. No such change occurs for the blue field.

Table 75. Pitch angle rate as a function of runway surround color and scene complexity at 1 nautical mile.

	Red Field	Blue Field	
Mean	0.128	0.104	
S.D.	0.353	0.386	Simple
Mean	0.013	0.105	
S.D.	0.324	0.326	Complex

This interaction may be explained by referring back to Figure 12, (page 68) which shows the glideslope deviation for the three different chromostereoscopic groups under conditions of the field color and the complexity of the scene. The red advancing group, flying against the simple scene with the red surround, and also the complex scene with the blue surround, is decreasing the rate of descent. The neutral group is also changing the rate of descent for the simple scene and blue surround. However, for the complex scene, with the red surround, all the groups seem not to be changing the rate of descent. This is reflected in their holding the pitch angle rate constant.

Pitch angle rate is significantly different as a function of surround color, scene complexity, and chromostereoscopic groups. As a second order interaction the trend in means is interesting as the pitch angle rate is consistently lower for the complex scene versus the simple scene for the BA and N groups when the surround color is red. The converse is true when the surround color is blue. The RA group inverts the trend by showing an increase in pitch angle rate (PAR) with red surround, complex scene, combination and a decreased PAR for the blue surround and complex scene.

The apparent reversal of the BA and N group trends by the RA group can be explained by where the sample was taken for the analysis. The larger PAR observed for the RA group flying toward the complex/red surround scene, comes just as a decrease in the rate of descent is spotted (Figure 11). Against the simple/red surround, a decrease in descent rate is continuing, probably controlled by pitch of the aircraft. The RA group flying toward the blue/simple scene is also just slowing the glideslope deviation by changing pitch rate at one nautical mile. The RA, blue complex scene combination is sampled just after a pitch change is complete and the glideslope deviation is neutral, therefore the low PAR is reflecting no further rate change. Thus, the explanation for specific PARs has to be in terms of when and where the sampling is drawn for the analysis.

Significant PARs may be most indicative of dynamic actions occurring at specific sampling intervals. Such a dependent measure may be more helpful if reported as frequencies of occurrence at specific intervals of magnitudes of change.

True Airspeed

True airspeed was studied as a dependent measure only once in a touchdown analysis. The main effect of color of the surround almost reached our criterion of significance with a $P = <.06$. The average speed was slower (239.4 ft sec.) and less variable (9.5 ft/sec.) with the red color surrounding the runway. This translates into 141.86 knots (standard deviation equals 5.67 knots) and compares with that for the blue color runway surround, having a mean speed of 143.22 knots and a standard deviation of 6.99 knots.

Longitudinal Touchdown Distance

Three touchdown analyses were conducted: (a) One at a sampling interval of 0.450 milliseconds before touchdown; (b) The second at touchdown and adjusted for the influence of pitch angle, the position of the aircraft sensor, degree of gear compression, change of algebraic sign and made relative to the 1000 ft. touchdown goal; (c) The same as (B) except using the dependent measure of glideslope deviation.

Since the means of the adjusted analysis of variance are relative to the point that the pilots were instructed to touch down, these are reported. The parallel analysis, (A) above, gave the same indications of significance , but had means relative to the electronic glideslope intercept.

The color of the runway surrounds as a main effect was significant.

Table 76. Touchdown distance as a function of color of runway surrounds.

	Red Surround	Blue Surround
Means	255.167	357.603
S.D.	835.439	906.142

The red surround touchdowns averaged 255.2 feet beyond the specified 1000 ft. touchdown goal. The variability was high as the standard deviation was 835 ft. The mean touchdown for the blue surround was 102.4 ft. further down the runway and the variability was higher than with the red surround.

No exactly comparable data exists as to the variability of pilots making visual approaches without altimetry, glideslope information, and vertical speed indication. The nearest is the data gathered on 16 USAF/MATS pilots flying the 727 simulator to the Compuscene displays in the investigation of the effects of windshield quality (Kraft, Anderson, Elworth & Larry, 1977). These pilots, flying to the same resolution scene, landed 87 ft. long and had a standard deviation of 749 ft. These pilots had two advantages over those reported in this study; (1) they had runway marks including, centerline, edge marks, and the 1000 ft. designator, and (2) they were flying a smaller and lighter airplane.

A first order interaction was significant, that of the color of the surround interacting with the chromostereopsis grouping of the pilots.

Table 77. Longitudinal touchdown distance as a function of color of the surround and grouping of pilots by chromostereopsis.

	Red Surround	Blue Surround	
Mean	285.045	415.589	
S.D.	834.299	829.454	Blue Advancing
Mean	-165.323	156.247	
S.D.	685.649	904.610	Neutral
Mean	645.777	500.973	
S.D.	790.410	965.899	Red Advancing

Figure 14 illustrates the relationships of this interaction. The neutral group, flying to the red surround, have an average touchdown 165 ft. short of the desired goal. Their variation is the smallest of all groups by conditions, with the red surround. The N group also touches down nearest the goal with the blue color, but in this instance, their variation is more than 200 ft. larger than it is with the red color. Regarding the means, the neutral group followed the original hypothesis; their touchdown position would be least affected by the surround color.

The BA group landed longer when flying toward the blue color surround and their variability is about a match for both surround hues.

The red advancing group landed longer when flying toward the red surround color and had less variability with this hue. The red advancing group reverses the trend found for the BA and N groups. That is, the BA and N groups landed further down the runway against the blue scene. The hypothesis based on chromostereopsis would predict the result found with the BA and RA groups, being about equally affected when the runway and surround were of matching hue. The hypothesis would predict that, when the blue advancing group were flying to the red surround, they would see the blue/black macadam runway above the surround and would land shorter. For the red advancing group, the hypothesis is that, since red is advancing for them, this group would see the surround higher than the blue/black macadam runway and land longer. These two developments of the hypothesis are also supported by these data.

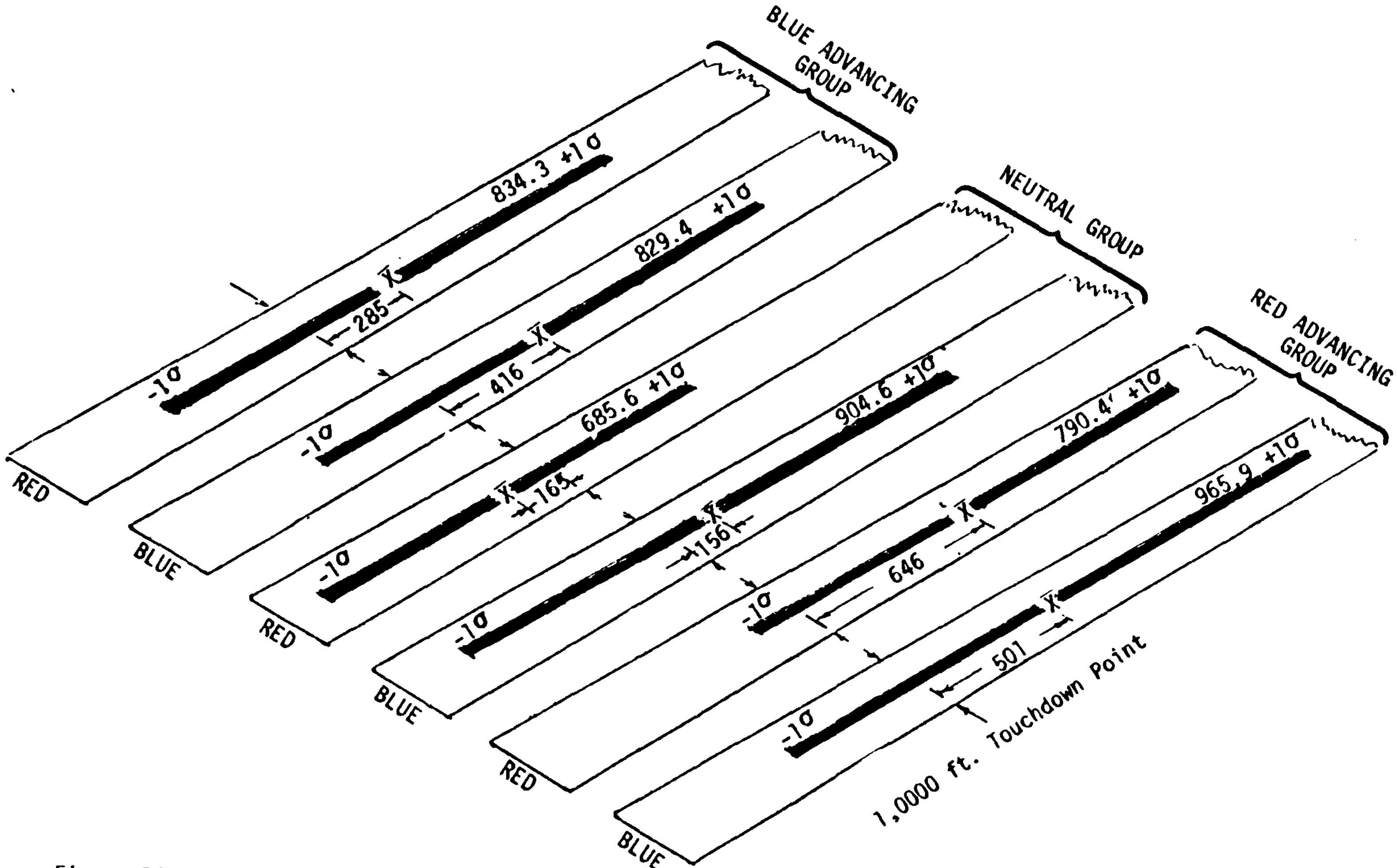

Figure 14. Touchdown point as influenced by chromostereopsis grouping and color of runway surround.

CONCLUSIONS - EXPERIMENT #3

Experiment 3 dealt with the main effects of color of the runway surround, scene complexity and pilots grouped by their chromostereopsis. These main effects were each significant at one or more of the analyses.

Chromostereopsis Groups

The chromostereopsis groups were three, each comprised of five pilots, stratified by the quantity and direction of their personal chromostereopsis. The "blue advancing" (BA) group had a mean of 48.1 arc seconds of stereoscopic spatial displacement of blue objects in front of red objects when viewed against a black field. This displacement is due to hue as luminous intensity was matched and size was systematically varied. The neutral (N) group was neutral as to displacement due to hue. The mean was 6 arc seconds with red advancing as a direction. The red advancing (RA) group's mean chromostereopsis was 48.2 arc seconds with red appearing in front of blue. The groups were all USAF/MATS pilots, current in C-141s and flying for the first time a 747 simulator.

Scene Complexity

The G.E. Compuscene 4000 was used with a daytime, trichromatic computer generated scene with two levels of complexity. The simple scene was that of a 13,500 ft. long, 300 ft. wide homogeneous blue/black macadam runway. The hue was on the Munsell color notation 10B, value 2.0 and chroma of 1.0 with a luminous intensity of 0.3 ftL. No runway marks were used throughout the study.

The complex scene differed in that objects and surfaces were visible in the runway surround up to the limit of 333 edges per 30° x 40° channel. Perceptual differentiation of these objects and surfaces were altered by changing saturation (chroma) without varying hue and luminous intensity.

Surround Color

The two levels were: A red surround with the basic surface a Munsell hue of 10R, value of 5.0 chroma of 16 at 0.9 ftL of intensity. In the complex scene other objects were designated by one of the five equal chroma steps from 12 through 4. The blue surround had a Munsell hue of 10B, a value of 5, a chroma of 10 and luminous intensity of 0.9 ftL. In the complex scene the chroma steps were 8, 6, 4 and 2.

Method

A new Redifon 747 simulator with a 6 degree of freedom motion base was used in performing the 16 straight in approaches completed by 15 USAF/MATS pilots. Strictly visual approaches were required by the absence of altimetry, vertical speed indication and glideslope aids. Magnetic tape records of 37 variables were taken every 450 milliseconds.

These magnetic records were transformed for a VAX computer series of analyses. ANOVAS were completed at four distances from the runway/ electronic glideslope intercept, two beyond and two inside of that distance where the lateral expansion of the runway width would become a dynamic perception. Two sets of ANOVAS were completed at touchdown.

The pilots flew from the left, or captain's seat with a field of view (FOV) of 30° vertically and a lateral FOV of 112° to the left and 20° to the right. The 16 approaches were prescheduled as a nearly balanced order so that each pilot made four consecutive approaches under each condition. The experimental design was a factorial 2 x 2 x 2 x 5 x 3 with the 5 pilots nested within the three chromostereopsis groups.

The point of touchdown along the runway was significantly different for the interaction between chromostereoscopic groups and runway surround color. The main effect of runway surround color was also significant. The average touchdown distance being 357.7 ft. with the blue surround and 255.2 ft. with the red surround. These are distances beyond the 1000 ft. touchdown goal set by the instructions given to the pilots. The hypothesis under test was supported by the interaction. The red advancing group landed longer when landing with a red surround color. The blue advancing and neutral group landed further down the runway with a blue surround. The neutral group touched down nearest the 1000 foot distance and appeared to be least affected by the color of the surround. This result would be predicted by the hypothesis as this group has the least stereoscopic displacement due to hue. The BA and RA have about equal but opposite direction in this average chromostereopsis. They have a touchdown distance of BA being long by 416 ft. and RA long by 501 ft. when the runway dominant wavelength (hue) and surround dominant wavelength (hue are the same.

The RA group lands longer (646 ft.) and the BA group shorter (285 ft.) when the runway dominant wavelength is short (blue) and the runway surround hue is characterized by a long dominant wavelength (red). The hypothesis would predict this greater difference when the runway and surround are of different hues. The direction of shift from the average touchdown position established with a common color was also predicted.

The largest variance found in the touchdown analysis of vertical velocity is also supportive of different performance by pilots flying toward different runway and surround colors.

Altitude and glideslope deviation were not significant at those distances where a dynamic perception of the runway expansion is possible. In this instance these analyses were made at 1/2 and 1 NM. However beyond the dynamic runway expansion perception threshold distance, the altitude and glideslope deviation are significantly different among trials and trials by scene complexity. The BA group maintained an altitude that placed them above the glideslope for a longer portion of the flight. The neutral group was neutral in respect to surround color but did fly higher with the complex scene. The red advancing group consistently flew closer to the glideslope at all distances. In addition a trend was noticed that the variance in glideslope deviation was smaller for all groups when the flights were made toward the runway with a red surround.

The variables of vertical velocity, pitch angle, and pitch angle rate show significant differences at the 1 and 1/2 NM distances most frequently as an interaction between scene complexity and color of the runway surround. These may differ in absolute amounts as a function of where, in distance, the sample is taken.

It may be concluded that color of the area surrounding the runway is a significant variable when it contrasts in hue with the runway color. This effect may be measurable only when one includes the division of the pilot population into chromostereopsis groups. Scene complexity as a dimension will modulate the above effect more in variance than in shifts of the means. Runway surround color interacts with scene complexity more within the approach distance of one nautical mile or less, than for greater distances from the runway. Altitude and glideslope deviation are more likely to be altered by scene color and complexity at distances of 2 to 3 miles from the runway. The touchdown distance along the runway and the glideslope deviations at two to three miles from the runway, are consistent with the hypothesis that: pilots, grouped by their personal chromostereopsis, will perceive their relative altitude differently as a function of the hue of the runway surround. These data are not as consistent when the hypothesis is applied to perceived distance, i.e. short range of the runway.

These conclusions, without further evidence, should be restricted to performance with computer generated images in simulators with the current limited range of luminous intensities. In the real world of flight with the atmospheric desaturation of color and the very wide range of luminous intensities, these effects may be modulated. However, this caution does not exclude color as an important variable, as color may add or detract from transfer of training from simulators to aircraft.

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APPENDIX A

DEMOGRAPHIC INFORMATION ON PILOTS

APPENDIX

Visual skills, age and experience of participating MATS pilots.

#	PILOT Age/Hrs. Exp./Rank	Chromo-stereopsis		STEREOPSIS Achrom	STEREOPSIS Chrom	STEREOPSIS Diff.	Color Discrim. Total	VISUAL ACUITY Far Right	VISUAL ACUITY Far Left	VISUAL ACUITY Near Both	Phoria Far	Experiment Participation
13	43/6000/Lt.C.	63	B	50	60	+10	30	0.5	0.5	0.7	E-1	1, 2, 3
6	26/1210/Capt.	48	B	>60	>60	0	36	0.5	0.9	0.7	0	1, 2, 3
10	41/8000/Maj.	48	B	21	10	-11	20	0.5	0.5	0.7	E-1	1, 2, 3
5	27/1150/Capt.	42	B	28	28	0	12	0.5	0.5	0.7	0	1, 2, 3
7	37/ 800/Maj.	40	B	10	29	+19	36	0.5	0.9	0.7	0	1, 2, 3
4	27/1000/Capt.	3.5	B	6	21	+15	36	0.5	0.5	0.7	E-1	1, 2, 3
14	33/ 450/Maj.	6.2	R	6	9	+ 3	28	0.5	0.5	0.7	0	1, 2, 3
16	26/1150/Capt.	13.3	R	6	10	+ 4	36	0.5	0.5	0.7	0	1, 2, 3
20	37/1400/Maj.	4.4	B	6	-	-	28	0.5	0.5	0.7	0	1, 2, 3
22	41/6500/Maj.	6.2	B	11	-	-	40	0.5	0.5	0.7	E-1	1, 2, 3
2	28/ 600/Lt.	62.2	R	8	29	+21	12	0.5	0.5	0.7	0	1, 2, 3
15	32/ 250/Capt.	59.6	R	21	>60	+59	10	0.5	0.5	0.7	0	1, 2
11	30/1950/Capt.	54	R	10	38	+28	16	0.5	0.5	0.7	E-1	3
12	28/1000/Lt.	46.2	R	8	56	+48	84	0.9	0.5	0.7	0	1, 2, 3
9	29/ 600/Capt.	40	R	29	60	+31	8	0.9	0.9	0.85	X-1	1, 2, 3
23	44/4500/L.Col.	38.2	R	6	-	-	12	0.5	1.0	0.7	0	1, 2, 3
3	43/3800/L.Col.	34.7	R	13	45	+32	24	2.5	0.5	0.85	0	1, 2
18	29/1600/Capt.	33.8	R	20	-	-	-	-	-	-	-	
17	28/2400/Capt.	29.3	R	3	-	-	-	-	-	-	-	
8	34/3300/Capt.	7.9	B	3	9	+ 6	-	-	-	-	-	
25	29/2800/Capt.	13.3	B	29	-	-	-	-	-	-	-	
1	30/2050/Capt.	18.7	B	15	20	+ 5	-	-	-	-	-	
24	37/5500/Maj.	17.8	B	7	-	-	-	-	-	-	-	
21	37/5300/Maj.	152.4	B	6	-	-	8	0.5	0.5	0.85	X-1	
19	30/1200/Capt.	11.5	R	>60	-	-	-	-	-	-	-	
		(arc sec)		(arc seconds)			(100 hue test units)	(arc minutes)			(diopters)	

APPENDIX B

ANALYSIS OF VARIANCE SUMMARY TABLES FOR EXPERIMENT #1

Table B-1. Peripheral cues and color - experiment #1 at 1 NM (LATD) into flight - dependent variable = altitude (H).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	78391.032	3	26130.344	F(3,45) =	5.13, P = 0.004 **
F	14706.648	1	14706.648	F(1,15) =	0.94, P = 0.348
TF	9512.542	3	3170.847	F(3,45) =	0.48, P = 0.699
S	13672.849	1	13672.849	F(1,15) =	0.45, P = 0.512
TS	13670.100	3	4556.700	F(3,45) =	0.81, P = 0.493
FS	31076.143	1	31076.143	F(1,15) =	1.50, P = 0.240
TFS	32054.616	3	10684.872	F(3,45) =	1.22, P = 0.312
P	3532658.273	15			
ERR T	229017.128	45	5089.270		
ERR F	235097.746	15	15673.183		
ERR TF	298469.868	45	6632.664		
ERR S	453534.075	15	30235.605		
ERR TS	252331.542	45	5607.368		
ERR FS	311092.335	15	20739.489		
ERR TFS	392719.605	45	8727.102		
TOTAL	5898018.582	255			

* P < .05
** P < .01

Table B-2. Peripheral cues and color - experiment #1 at runway acqui. - dependent variable = altitude (H).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	144780.156	3	48260.055	F(3,45) =	2.22, P = 0.099
F	1877.636	1	1877.636	F(1,15) =	0.03, P = 0.858
TF	39379.160	3	13126.387	F(3,45) =	0.61, P = 0.615
S	30073.816	1	30073.816	F(1,15) =	0.19, P = 0.665
TS	143501.908	3	47833.969	F(3,45) =	2.31, P = 0.089
FS	592638.479	1	592638.479	F(1,15) =	5.84, P = 0.029 *
TFS	48504.478	3	16168.159	F(3,45) =	0.63, P = 0.602
P	6751697.059	15			
ERR T	978808.572	45	21751.302		
ERR F	846644.983	15	56442.999		
ERR TF	976200.201	45	21693.338		
ERR S	2318201.434	15	154546.762		
ERR TS	931208.855	45	20693.530		
ERR FS	1521770.866	15	101451.391		
ERR TFS	1163676.682	45	25859.482		
TOTAL	16488964.294	255			

* P < .05
** P < .01

Table B-3. Peripheral cues and color - experiment #1 at 4.55 NM out - dependent variable = altitude (H).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	210810.331	3	70270.110	F(3,45) =	2.70, P = 0.057
F	15302.149	1	15302.149	F(1,15) =	0.19, P = 0.667
TF	49963.898	3	16654.633	F(3,45) =	0.67, P = 0.576
S	36184.654	1	36184.654	F(1,15) =	0.21, P = 0.653
TS	147048.988	3	49016.329	F(3,45) =	1.70, P = 0.180
FS	795055.338	1	795055.338	F(1,15) =	6.56, P = 0.022 *
TFS	66592.437	3	22197.479	F(3,45) =	0.72, P = 0.544
P	5620523.144	15			
ERR T	1170680.646	45	26015.125		
ERR F	1193529.549	15	79568.637		
ERR TF	1121409.739	45	24920.216		
ERR S	2581217.469	15	172081.165		
ERR TS	1297471.189	45	28832.693		
ERR FS	1817319.673	15	121154.645		
ERR TFS	1384509.893	45	30766.887		
TOTAL	17507619.007	255			

* P < .05
** P < .01

Table B-4. Peripheral cues and color - experiment #1 at 4.55 NM out - dependent variable = rate of climb (ROC).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	140.569	3	46.856	F(3,45) =	1.91, P = 0.142
F	39.726	1	39.726	F(1,15) =	2.56, P = 0.130
TF	29.860	3	9.953	F(3,45) =	0.54, P = 0.657
S	3.287	1	3.287	F(1,15) =	0.11, P = 0.747
TS	57.573	3	19.191	F(3,45) =	1.33, P = 0.278
FS	4.097	1	4.097	F(1,15) =	0.11, P = 0.748
TFS	24.709	3	8.236	F(3,45) =	0.50, P = 0.687
P	3913.385	15			
ERR T	1104.367	45	24.541		
ERR F	232.612	15	15.507		
ERR TF	829.459	45	18.432		
ERR S	457.774	15	30.518		
ERR TS	651.695	45	14.482		
ERR FS	572.548	15	38.170		
ERR TFS	747.006	45	16.600		
TOTAL	8808.666	255			

* P < .05
** P < .01

Table B-5. Peripheral cues and color - experiment #1 at runway acquisition - dependent variable = rate of climb (ROC).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	56.158	3	18.719	F(3,45) =	1.07, P = 0.373
F	11.130	1	11.130	F(1,15) =	0.21, P = 0.652
TF	26.088	3	8.696	F(3,45) =	0.39, P = 0.757
S	21.565	1	21.565	F(1,15) =	0.39, P = 0.544
TS	30.291	3	10.097	F(3,45) =	0.57, P = 0.637
FS	292.118	1	292.118	F(1,15) =	4.68, P = 0.047 *
TFS	74.420	3	24.807	F(3,45) =	1.58, P = 0.207
P	1002.998	15			
ERR T	790.603	45	17.569		
ERR F	786.678	15	52.445		
ERR TF	991.385	45	22.031		
ERR S	838.420	15	55.895		
ERR TS	795.288	45	17.673		
ERR FS	935.440	15	62.363		
ERR TFS	706.014	45	15.689		
TOTAL	8150.595	255			

* P < .05
** P < .01

Table B-6. Peripheral cues and color - experiment #1 at 1 NM (LATD) into flight - dependent variable = distance from 1840' mark (LONG).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	1389411.156	3	463137.052	F(3,45) =	2.55, P = 0.067
F	1457307.470	1	1457307.470	F(1,15) =	10.07, P = 0.006 **
TF	1905800.416	3	635266.805	F(3,45) =	1.88, P = 0.146
S	1272377.443	1	1272377.443	F(1,15) =	7.52, P = 0.015 *
TS	1336333.123	3	445444.374	F(3,45) =	1.54, P = 0.218
FS	304016.507	1	304016.507	F(1,15) =	0.65, P = 0.433
TFS	1281872.028	3	427290.676	F(3,45) =	1.84, P = 0.153
P	27220473.535	15			
ERR T	8163800.151	45	181417.781		
ERR F	2171146.386	15	144743.092		
ERR TF	15166055.962	45	337023.466		
ERR S	2537621.854	15	169174.790		
ERR TS	13185703.873	45	293015.642		
ERR FS	7009951.456	15	467330.097		
ERR TFS	10445990.161	45	232133.115		
TOTAL	94712861.520	255			

* P < .05
** P < .01

Table B-7. Peripheral cues and color - experiment #1 - lateral distance = 8850 - dependent variable = log of the variance of distance from 1840 mark.

LABEL	FACTOR	NO. LEVELS
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
F	0.100	1	0.100	F(1,15) =	0.08, P = 0.784
S	2.483	1	2.483	F(1,15) =	1.13, P = 0.304
FS	5.975	1	5.975	F(1,15) =	1.23, P = 0.285
P	44.035	15			
ERR F	19.206	15	1.280		
ERR S	32.905	15	2.194		
ERR FS	73.040	15	4.869		
TOTAL	177.743	63			

* P < .05
** P < .01

Table B-8. Peripheral cues and color - experiment #1 - at longitude = 32100 - dependent variable = lateral deviation regarding signs.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	17007115.934	3	5669038.645	F(3,45) =	3.11, P = 0.036 *
F	22959783.283	1	22959783.283	F(1,15) =	9.65, P = 0.007 **
TF	14944609.504	3	4981536.501	F(3,45) =	2.17, P = 0.104
S	1441637.610	1	1441637.610	F(1,15) =	0.62, P = 0.444
TS	4118512.293	3	1372837.431	F(3,45) =	0.93, P = 0.433
FS	715891.207	1	715891.207	F(1,15) =	0.26, P = 0.616
TFS	1498467.170	3	499489.057	F(3,45) =	0.21, P = 0.890
P	97754445.182	15			
ERR T	82020343.134	45	1822674.292		
ERR F	35697110.043	15	2379807.870		
ERR TF	103188163.391	45	2293070.298		
ERR S	34928095.895	15	2328539.726		
ERR TS	66198867.239	45	1471085.939		
ERR FS	40998658.929	15	2733243.929		
ERR TFS	107728155.015	45	2393959.000		
TOTAL	631199863.020	255			

* P < .05
** P < .01

Table B-9. Peripheral cues and color - experiment #1 at runway acquisition - dependent variable = lateral deviation disregarding signs.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	6704923.616	3	2234974.539	F(3,45) =	3.41, P = 0.025 *
F	36411343.282	1	36411343.282	F(1,15) =	18.81, P = 0.001 **
TF	6054865.795	3	2018288.598	F(3,45) =	2.01, P = 0.126
S	4898265.223	1	4898265.223	F(1,15) =	1.91, P = 0.187
TS	5792379.765	3	1930793.255	F(3,45) =	1.58, P = 0.207
FS	848637.502	1	848637.502	F(1,15) =	0.72, P = 0.409
TFS	1956222.366	3	652074.122	F(3,45) =	0.57, P = 0.639
P	38770496.262	15			
ERR T	29531124.156	45	656247.203		
ERR F	29042978.852	15	1936198.590		
ERR TF	45223548.472	45	1004967.744		
ERR S	38388620.533	15	2559241.369		
ERR TS	55008095.280	45	1222402.116		
ERR FS	17604341.653	15	1173622.777		
ERR TFS	51656853.341	45	1147930.074		
TOTAL	367892696.018	255			

* P < .05
** P < .01

Table B-10. Peripheral cues and color - experiment #1 - Longitude = 32100 - dependent variable = lateral deviation regarding signs.

LABEL	FACTOR	NO. LEVELS
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
F	30.864	1	30.864	F(1,15) =	14.14, P = 0.002 **
S	8.420	1	8.420	F(1,15) =	3.09, P = 0.099
FS	0.934	1	0.934	F(1,15) =	0.76, P = 0.398
P	44.649	15			
ERR F	32.729	15	2.182		
ERR S	40.934	15	2.729		
ERR FS	17.876	15	1.192		
TOTAL	176.376	63			

* P < .05
** P < .01

Table B-11. Peripheral cues and color - experiment #1 - at 4.55 NM out (Long = 27646) - dependent variable = lateral deviation regarding signs.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	5950068.346	3	1983356.115	F(3,45) =	1.83, P = 0.155
F	8443043.384	1	8443043.384	F(1,15) =	6.22, P = 0.025 *
TF	7528444.061	3	2509481.354	F(3,45) =	2.19, P = 0.102
S	343692.919	1	343692.919	F(1,15) =	0.36, P = 0.557
TS	1465575.921	3	488525.307	F(3,45) =	0.42, P = 0.738
FS	46647.042	1	46647.042	F(1,15) =	0.04, P = 0.836
TFS	910719.647	3	303573.282	F(3,45) =	0.21, P = 0.888
P	40671945.928	15			
ERR T	48694114.798	45	1082091.440		
ERR F	20352747.335	15	1356849.822		
ERR TF	51573914.723	45	1146086.994		
ERR S	13887826.136	15	925855.074		
ERR TS	52117119.647	45	1158158.192		
ERR FS	15832541.658	15	1055508.111		
ERR TFS	64515311.035	45	1433673.579		
TOTAL	332323671.530	255			

* P < .05
** P < .01

Table B-12. Peripheral cues and color - experiment #1 at 4.55 NM out - dependent variable = lateral deviation disregarding signs.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	4936757.747	3	1645585.916	F(3,45) =	3.82, P = 0.016 *
F	36192221.558	1	36192221.558	F(1,15) =	44.00, P = 0.000 **
TF	5291699.655	3	1763899.885	F(3,45) =	3.04, P = 0.038 *
S	4832902.654	1	4832902.654	F(1,15) =	4.49, P = 0.051
TS	2097162.397	3	699054.132	F(3,45) =	1.56, P = 0.212
FS	2016063.403	1	2016063.403	F(1,15) =	4.04, P = 0.063
TFS	2625511.656	3	875170.552	F(3,45) =	1.73, P = 0.175
P	9248530.625	15			
ERR T	19399747.285	45	431105.495		
ERR F	12337758.384	15	822517.226		
ERR TF	26082801.747	45	579617.817		
ERR S	16161687.965	15	1077445.864		
ERR TS	20141975.569	45	447599.457		
ERR FS	7489491.718	15	499299.448		
ERR TFS	22801774.804	45	506706.107		
TOTAL	191656087.168	255			

* P < .05
** P < .01

Table B-13. Peripheral cues and color - experiment #1 - long = 27646 - dependent variable = lateral deviation regarding signs.

LABEL	FACTOR	NO. LEVELS
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
F	84.454	1	84.454	F(1,15) =	39.18, P = 0.000 **
S	9.676	1	9.676	F(1,15) =	3.80, P = 0.070
FS	0.038	1	0.038	F(1,15) =	0.01, P = 0.925
P	26.517	15			
ERR F	32.337	15	2.156		
ERR S	38.228	15	2.549		
ERR FS	13.158	15	0.877		
TOTAL	204.378	63			

* P < .05
** P < .01

Table B-14. Peripheral cues and color - experiment #1 at 4.55 NM out - dependent variable = true airspeed.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	136.676	3	45.559	F(3,45) =	0.73, P = 0.538
F	5.419	1	5.419	F(1,15) =	0.03, P = 0.856
TF	131.222	3	43.741	F(3,45) =	0.68, P = 0.570
S	4.259	1	4.259	F(1,15) =	0.02, P = 0.888
TS	233.866	3	77.955	F(3,45) =	1.17, P = 0.333
FS	80.360	1	80.360	F(1,15) =	0.44, P = 0.518
TFS	215.445	3	71.815	F(3,45) =	1.38, P = 0.261
P	11059.780	15			
ERR T	2799.857	45	62.219		
ERR F	2388.343	15	159.223		
ERR TF	2900.512	45	64.456		
ERR S	3088.842	15	205.923		
ERR TS	3008.451	45	66.854		
ERR FS	2752.905	15	183.527		
ERR TFS	2340.974	45	52.022		
TOTAL	31146.912	255			

* P < .05
** P < .01

Table B-15. Peripheral cues and color - experiment #1 at 4.55 NM out - dependent variable = pitch angle in degrees.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	8.890	3	2.963	F(3,45) =	1.61, P = 0.199
F	1.918	1	1.918	F(1,15) =	1.02, P = 0.328
TF	0.128	3	0.043	F(3,45) =	0.04, P = 0.990
S	1.113	1	1.113	F(1,15) =	0.36, P = 0.555
TS	4.354	3	1.451	F(3,45) =	0.93, P = 0.436
FS	0.445	1	0.445	F(1,15) =	0.12, P = 0.737
TFS	1.713	3	0.571	F(3,45) =	0.49, P = 0.689
P	482.797	15			
ERR T	82.637	45	1.836		
ERR F	28.123	15	1.875		
ERR TF	52.405	45	1.165		
ERR S	45.757	15	3.050		
ERR TS	70.521	45	1.567		
ERR FS	56.838	15	3.789		
ERR TFS	52.216	45	1.160		
TOTAL	889.806	255			

* P < .05
** P < .01

Table B-16. Peripheral cues and color - experiment #1 at 4.55 NM out (Long = 27646) - dependent variable = pitch angle rate (degrees/seconds).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	0.615	3	0.205	F(3,45) =	1.24, P = 0.307
F	0.317	1	0.317	F(1,15) =	1.46, P = 0.246
TF	0.456	3	0.152	F(3,45) =	0.93, P = 0.432
S	0.008	1	0.008	F(1,15) =	0.03, P = 0.870
TS	0.915	3	0.305	F(3,45) =	1.34, P = 0.272
FS	0.137	1	0.137	F(1,15) =	0.83, P = 0.377
TFS	0.066	3	0.022	F(3,45) =	0.10, P = 0.961
P	1.983	15			
ERR T	7.452	45	0.166		
ERR F	3.262	15	0.217		
ERR TF	7.311	45	0.162		
ERR S	4.085	15	0.272		
ERR TS	10.217	45	0.227		
ERR FS	2.480	15	0.165		
ERR TFS	10.092	45	0.224		
TOTAL	49.396	255			

* P < .05
** P < .01

Table B-17. Peripheral cues and color - experiment #1 at 1 NM (LATD) into flight - dependent variable = roll angle in degrees.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	339.789	3	113.263	F(3,45) =	4.73, P = 0.006 **
F	167.467	1	167.467	F(1,15) =	9.45, P = 0.008 **
TF	91.418	3	30.473	F(3,45) =	1.46, P = 0.238
S	18.416	1	18.416	F(1,15) =	1.18, P = 0.294
TS	55.232	3	18.411	F(3,45) =	0.88, P = 0.460
FS	48.961	1	48.961	F(1,15) =	0.97, P = 0.340
TFS	79.798	3	26.599	F(3,45) =	1.35, P = 0.270
P	2772.271	15			
ERR T	1078.505	45	23.967		
ERR F	265.833	15	17.722		
ERR TF	938.140	45	20.848		
ERR S	234.073	15	15.605		
ERR TS	945.371	45	21.008		
ERR FS	755.655	15	50.377		
ERR TFS	886.028	45	19.690		
TOTAL	8676.951	255			

* P < .05
** P < .01

Table B-18. Peripheral cues and color - experiment #1 at runway acquisition - dependent variable = roll angle in degrees.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	55.131	3	18.377	F(3,45) =	0.66, P = 0.579
F	122.838	1	122.838	F(1,15) =	2.77, P = 0.117
TF	93.950	3	31.317	F(3,45) =	0.95, P = 0.425
S	2.783	1	2.783	F(1,15) =	0.05, P = 0.821
TS	28.237	3	9.412	F(3,45) =	0.52, P = 0.672
FS	254.695	1	254.695	F(1,15) =	6.89, P = 0.019 *
TFS	52.103	3	17.368	F(3,45) =	0.54, P = 0.658
P	1512.740	15			
ERR T	1247.195	45	27.715		
ERR F	666.355	15	44.424		
ERR TF	1485.098	45	33.002		
ERR S	765.824	15	51.055		
ERR TS	818.203	45	18.182		
ERR FS	554.863	15	36.991		
ERR TFS	1450.777	45	32.239		
TOTAL	9110.712	255			

* P < .05
** P < .01

Table B-19. Peripheral cues and color - experiment #1 - at 4.55 NM out (Long = 27646) - dependent variable = roll angle in degrees.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	10.846	3	3.615	F(3,45) =	0.28, P = 0.838
F	16.654	1	16.654	F(1,15) =	0.72, P = 0.409
TF	93.711	3	31.237	F(3,45) =	1.18, P = 0.327
S	105.528	1	105.528	F(1,15) =	6.91, P = 0.019 *
TS	66.333	3	22.111	F(3,45) =	1.72, P = 0.177
FS	28.598	1	28.598	F(1,15) =	1.49, P = 0.242
TFS	18.361	3	6.120	F(3,45) =	0.36, P = 0.781
P	1482.128	15			
ERR T	575.847	45	12.797		
ERR F	346.489	15	23.099		
ERR TF	1187.659	45	26.392		
ERR S	228.960	15	15.264		
ERR TS	574.750	45	12.861		
ERR FS	287.923	15	19.195		
ERR TFS	761.037	45	16.912		
TOTAL	5708.733	255			

* P < .05
** P < .01

Table B-20. Peripheral cues and color - experiment #1 at 1 NM (LATD) into flight - dependent variable = roll angle rate (degrees/second).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	1.990	3	0.663	F(3,45) =	0.32, P = 0.808
F	0.322	1	0.322	F(1,15) =	0.11, P = 0.741
TF	8.763	3	2.921	F(3,45) =	1.03, P = 0.155
S	1.993	1	1.993	F(1,15) =	0.79, P = 0.387
TS	6.478	3	2.159	F(3,45) =	0.77, P = 0.515
FS	0.059	1	0.059	F(1,15) =	0.03, P = 0.876
TFS	7.674	3	2.558	F(3,45) =	1.03, P = 0.388
P	106.303	15			
ERR T	92.085	45	2.046		
ERR F	42.808	15	2.854		
ERR TF	71.680	45	1.593		
ERR S	37.702	15	2.513		
ERR TS	125.762	45	2.795		
ERR FS	34.636	15	2.309		
ERR TFS	111.665	45	2.481		
TOTAL	649.919	255			

* P < .05
** P < .01

Table B-21. Peripheral cues and color - experiment #1 - at 4.55 NM out (Long = 27646) - dependent variable = roll angle rate (degrees/second).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	2.194	3	0.731	F(3,45) =	0.27, P = 0.847
F	1.259	1	1.259	F(1,15) =	0.74, P = 0.404
TF	11.047	3	3.682	F(3,45) =	0.98, P = 0.409
S	6.332	1	6.332	F(1,15) =	2.26, P = 0.153
TS	8.131	3	2.710	F(3,45) =	0.81, P = 0.494
FS	0.030	1	0.030	F(1,15) =	0.02, P = 0.902
TFS	18.758	3	6.253	F(3,45) =	2.13, P = 0.110
P	79.642	15			
ERR T	122.282	45	2.717		
ERR F	25.552	15	1.703		
ERR TF	168.384	45	3.742		
ERR S	41.983	15	2.799		
ERR TS	150.059	45	3.335		
ERR FS	28.179	15	1.879		
ERR TFS	132.410	45	2.942		
TOTAL	796.242	255			

* P < .05
** P < .01

Table B-22. Peripheral cues and color - experiment #1 at 1 NM (LATD) into flight - dependent variable = heading in degrees.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	756.371	3	252.124	F(3,45) =	6.39, P = 0.001 **
F	628.557	1	628.557	F(1,15) =	14.62, P = 0.002 **
TF	383.766	3	127.922	F(3,45) =	1.95, P = 0.136
S	401.520	1	401.520	F(1,15) =	6.43, P = 0.023 *
TS	224.379	3	74.793	F(3,45) =	1.43, P = 0.245
FS	0.003	1	0.003	F(1,15) =	0.00, P = 0.997
TFS	268.316	3	89.439	F(3,45) =	1.34, P = 0.274
P	10034.863	15			
ERR T	1776.517	45	39.478		
ERR F	644.679	15	42.979		
ERR TF	2958.482	45	65.744		
ERR S	936.418	15	62.428		
ERR TS	2347.738	45	52.172		
ERR FS	2562.422	15	170.828		
ERR TFS	3005.234	45	66.782		
TOTAL	26929.235	255			

* P < .05
** P < .01

Table B-23. Peripheral cues and color - experiment #1 at runway acquisition - dependent variable = heading in degrees.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	409.024	3	136.341	F(3,45) =	2.99, P = 0.041 *
F	227.286	1	227.286	F(1,15) =	3.11, P = 0.098
TF	68.072	3	22.691	F(3,45) =	0.28, P = 0.841
S	787.493	1	787.493	F(1,15) =	13.03, P = 0.003 **
TS	41.600	3	13.867	F(3,45) =	0.28, P = 0.839
FS	10.278	1	10.278	F(1,15) =	0.05, P = 0.833
TFS	227.154	3	75.718	F(3,45) =	1.70, P = 0.181
P	16916.739	15			
ERR T	2052.175	45	45.604		
ERR F	1095.514	15	73.034		
ERR TF	3673.023	45	81.623		
ERR S	906.260	15	60.417		
ERR TS	2220.878	45	49.353		
ERR FS	3330.385	15	222.026		
ERR TFS	2007.251	45	44.606		
TOTAL	27973.131	255			

* P < .05
** P < .01

Table B-24. Peripheral cues and color - experiment #1 at 4.55 NM out - dependent variable = heading in degrees.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	493.131	3	164.377	F(3,45) =	3.42, P = 0.025 *
F	596.014	1	596.014	F(1,15) =	7.03, P = 0.018 *
TF	420.722	3	140.241	F(3,45) =	2.45, P = 0.076
S	145.262	1	145.262	F(1,15) =	1.97, P = 0.181
TS	65.059	3	21.686	F(3,45) =	0.50, P = 0.683
FS	194.919	1	194.919	F(1,15) =	3.13, P = 0.097
TFS	11.034	3	3.678	F(3,45) =	0.07, P = 0.977
P	3038.269	15			
ERR T	2162.609	45	48.060		
ERR F	1271.580	15	84.772		
ERR TF	2579.489	45	57.322		
ERR S	1105.296	15	73.686		
ERR TS	1943.038	45	43.179		
ERR FS	933.073	15	62.205		
ERR TFS	2448.328	45	54.407		
TOTAL	17407.892	255			

* P < .05
** P < .01

Table B-25. Peripheral cues and color - experiment #1 at 1 NM (LATD) into flight - dependent variable = *heading rate* (degrees/second).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	1.712	3	1.571	F(3,45) =	3.91, P = 0.015 *
F	2.088	1	2.088	F(1,15) =	5.17, P = 0.038 *
TF	1.293	3	0.431	F(3,45) =	1.29, P = 0.289
S	0.749	1	0.749	F(1,15) =	2.90, P = 0.109
TS	0.715	3	0.238	F(3,45) =	0.91, P = 0.446
FS	0.651	1	0.651	F(1,15) =	1.09, P = 0.313
TFS	0.618	3	0.206	F(3,45) =	0.67, P = 0.574
P	37.975	15			
ERR T	18.097	45	0.402		
ERR F	6.053	15	0.404		
ERR TF	15.044	45	0.333		
ERR S	3.879	15	0.259		
ERR TS	11.849	45	0.263		
ERR FS	8.945	15	0.596		
ERR TFS	13.830	45	0.307		
TOTAL	126.458	255			

* P < .05
** P < .01

Table B-26. Peripheral cues and color - experiment #1 at runway acquisition - dependent variable = heading rate (degrees/second).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	1.060	3	0.353	F(3,45) =	0.88, P = 0.460
F	1.572	1	1.572	F(1,15) =	2.33, P = 0.148
TF	1.090	3	0.363	F(3,45) =	0.73, P = 0.538
S	0.238	1	0.238	F(1,15) =	0.29, P = 0.601
TS	0.793	3	0.264	F(3,45) =	0.95, P = 0.426
FS	3.378	1	3.378	F(1,15) =	5.52, P = 0.033 *
TFS	0.077	3	0.026	F(3,45) =	0.05, P = 0.985
P	17.470	15			
ERR T	18.132	45	0.403		
ERR F	10.128	15	0.675		
ERR TF	22.324	45	0.496		
ERR S	12.494	15	0.833		
ERR TS	12.562	45	0.279		
ERR FS	9.183	15	0.612		
ERR TFS	22.993	45	0.511		
TOTAL	133.493	255			

* P < .05
** P < .01

Table B-27. Peripheral cues and color - experiment #1 - at 4.55 NM out (Long = 27646) - dependent variable = heading rate (degrees/second).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	0.077	3	0.026	F(3,45) =	0.10, P = 0.960
F	0.092	1	0.092	F(1,15) =	0.31, P = 0.585
TF	1.623	3	0.541	F(3,45) =	1.46, P = 0.238
S	1.292	1	1.292	F(1,15) =	4.67, P = 0.047 *
TS	1.835	3	0.612	F(3,45) =	2.56, P = 0.066
FS	0.794	1	0.794	F(1,15) =	3.71, P = 0.073
TFS	1.039	3	0.346	F(3,45) =	1.28, P = 0.294
P	23.977	15			
ERR T	11.615	45	0.258		
ERR F	4.425	15	0.295		
ERR TF	16.680	45	0.371		
ERR S	4.150	15	0.277		
ERR TS	10.733	45	0.239		
ERR FS	3.215	15	0.214		
ERR TFS	12.216	45	0.271		
TOTAL	93.762	255			

* P < .05
** P < .01

APPENDIX C

ANALYSIS OF VARIANCE SUMMARY TABLES FOR EXPERIMENT #2

This appendix does not include the ANOVA tables for distances considered individually since the analyses treating distance as an added independent variable effectively yield the same results.

Table C-1. Peripheral cues and color - experiment #2 at longitude = 12,6,&3 thousand feet - dependent variable = altitude.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16
D	DISTANCE	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	59968.242	3	19989.401	F(3,45) =	2.10, P = 0.113
F	30796.966	1	30796.966	F(1,15) =	1.66, P = 0.217
TF	38964.193	3	12988.064	F(3,45) =	1.30, P = 0.287
S	45948.735	1	45948.735	F(1,15) =	2.61, P = 0.127
TS	79878.735	3	26626.245	F(3,45) =	3.19, P = 0.032 *
FS	136384.063	1	136384.063	F(1,15) =	4.10, P = 0.061
TFS	8193.072	3	2731.024	F(3,45) =	0.39, P = 0.760
P	1169419.693	15			
D	22983411.308	2	11491705.654	F(2,30) =	1261.52, P = 0.000 **
TD	23775.368	6	3962.560	F(6,90) =	2.69, P = 0.019 *
FD	7466.735	2	3733.352	F(2,30) =	1.20, P = 0.316
TFD	12011.482	6	2001.914	F(6,90) =	1.30, P = 0.267
SD	17219.269	2	8609.634	F(2,30) =	4.27, P = 0.023 *
TSD	10026.881	6	1671.147	F(6,90) =	1.29, P = 0.270
FSD	23132.443	2	11566.221	F(2,30) =	2.67, P = 0.086
TFSD	2745.011	6	457.502	F(6,90) =	0.37, P = 0.898
ERR T	428101.619	45	9513.370		
ERR F	278033.682	15	18535.579		
ERR TF	450675.712	45	10015.016		
ERR S	263418.627	15	17561.242		
ERR TS	375461.628	45	8343.616		
ERR FS	497213.842	15	33147.589		
ERR TFS	314528.022	45	6989.512		
ERR D	273281.402	30	9109.380		
ERR TD	132466.520	90	1471.850		
ERR FD	93609.327	30	3120.311		
ERR TFD	138946.094	90	1543.845		
ERR SD	60544.324	30	2018.144		
ERR TSD	116748.973	90	1297.211		
ERR FSD	130034.767	30	4334.492		
ERR TFSD	112191.090	90	1246.568		
TOTAL	26334904.359	767			

* P < .05
** P < .01

Table C-2. Peripheral cues and color - experiment #2 at longitude = 12,6,&3 thousand feet - dependent variable = rate of climb.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16
D	DISTANCE	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	193.196	3	64.399	F(3,45) =	4.39, P = 0.009 **
F	41.041	1	41.041	F(1,15) =	1.59, P = 0.226
TF	157.359	3	52.453	F(3,45) =	2.90, P = 0.045 *
S	51.925	1	51.925	F(1,15) =	2.66, P = 0.124
TS	102.394	3	34.131	F(3,45) =	2.80, P = 0.051
FS	264.786	1	264.783	F(1,15) =	5.77, P = 0.030 *
TFS	22.294	3	7.431	F(3,45) =	0.50, P = 0.682
P	1724.062	15			
D	623.017	2	311.509	F(2,30) =	7.72, P = 0.002 **
TD	8.251	6	1.375	F(6,90) =	0.12, P = 0.994
FD	5.098	2	2.549	F(2,30) =	0.40, P = 0.674
TFD	24.968	6	4.161	F(6,90) =	0.33, P = 0.917
SD	234.686	2	117.343	F(2,30) =	11.42, P = 0.000 **
TSD	200.666	6	33.444	F(6,90) =	2.58, P = 0.023 *
FSD	78.135	2	39.067	F(2,30) =	2.25, P = 0.123
TFSD	52.667	6	8.778	F(6,90) =	0.92, P = 0.485
ERR T	660.320	45	14.674		
ERR F	386.349	15	25.757		
ERR TF	814.056	45	18.090		
ERR S	293.016	15	19.534		
ERR TS	549.154	45	12.203		
ERR FS	687.927	15	45.862		
ERR TFS	665.066	45	14.780		
ERR D	1210.632	30	40.354		
ERR TD	1071.760	90	11.908		
ERR FD	191.504	30	6.383		
ERR TFD	1118.833	90	12.432		
ERR SD	329.432	30	10.981		
ERR TSD	1171.170	90	13.013		
ERR FSD	520.166	30	17.339		
ERR TFSD	859.029	90	9.545		
TOTAL	14374.170	767			

* P < .05
** P < .01

Table C-3. Peripheral cues and color - experiment #2 at longitude = 12,6&3 thousand feet - dependent variable = glide slope deviation.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16
D	DISTANCE	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	2856.241	3	952.080	F(3,45) =	0.22, P = 0.883
F	763.784	1	763.784	F(1,15) =	0.23, P = 0.642
TF	2966.430	3	988.843	F(3,45) =	0.30, P = 0.828
S	100430.832	1	100430.832	F(1,15) =	14.01, P = 0.002 **
TS	5630.532	3	1880.177	F(3,45) =	0.57, P = 0.639
FS	1333.414	1	1333.414	F(1,15) =	0.26, P = 0.620
TFS	7276.373	3	2425.458	F(3,45) =	0.65, P = 0.587
P	353427.253	15			
D	364477.900	2	182238.950	F(2,30) =	41.87, P = 0.000 **
TD	6236.411	6	1311.432	F(6,90) =	0.96, P = 0.501
FD	7576.361	2	3788.181	F(2,30) =	2.92, P = 0.070
TFD	3099.188	6	516.531	F(6,90) =	0.56, P = 0.762
SD	17114.422	2	8557.211	F(2,30) =	5.11, P = 0.018 *
TSD	11571.768	6	1927.961	F(6,90) =	2.17, P = 0.053
FSD	4466.633	2	2233.317	F(2,30) =	1.72, P = 0.197
TFSD	9103.926	6	1517.154	F(6,90) =	1.25, P = 0.287
ERR T	196436.376	45	4365.251		
ERR F	50825.819	15	3388.454		
ERR TF	150017.219	45	3334.383		
ERR S	107501.885	15	7173.792		
ERR TS	147925.244	45	3287.227		
ERR FS	76371.488	15	5091.433		
ERR TFS	167834.973	45	3729.577		
ERR D	130573.836	30	4352.461		
ERR TD	103865.716	90	1153.440		
ERR FD	39087.796	30	1302.927		
ERR TFD	83114.560	90	921.513		
ERR SD	46175.419	30	1535.847		
ERR TSD	79903.423	90	887.742		
ERR FSD	39041.825	30	1301.394		
ERR TFSD	109157.510	90	1213.639		
TOTAL	2427962.512	767			

* P < .05
** P < .01

Table C-4. Peripheral cues and color - experiment #2 at longitude = 12,6,&3 thousand feet - dependent variable = aircraft pitch angle.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16
D	DISTANCE	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	15.435	3	5.145	F(3,45) =	1.83, P = 0.155
F	7.215	1	7.215	F(1,15) =	2.55, P = 0.131
TF	21.944	3	7.988	F(3,45) =	3.35, P = 0.027 *
S	2.534	1	2.534	F(1,15) =	1.27, P = 0.277
TS	7.321	3	2.440	F(3,45) =	1.24, P = 0.307
FS	10.001	1	10.001	F(1,15) =	2.45, P = 0.139
TFS	1.459	3	0.486	F(3,45) =	0.22, P = 0.885
P	1239.047	15			
D	111.744	2	55.870	F(2,30) =	22.73, P = 0.000 **
TD	3.359	6	0.513	F(6,90) =	0.63, P = 0.706
FD	2.148	2	1.074	F(2,30) =	1.18, P = 0.322
TFD	2.918	6	0.486	F(6,90) =	0.56, P = 0.759
SD	8.198	2	4.099	F(2,30) =	3.56, P = 0.041 *
TSD	15.657	6	2.609	F(6,90) =	3.00, P = 0.013 *
FSD	5.075	2	2.538	F(2,30) =	2.25, P = 0.123
TFSD	2.794	6	0.466	F(6,90) =	0.65, P = 0.688
ERR T	126.581	45	2.813		
ERR F	42.511	15	2.834		
ERR TF	107.328	45	2.385		
ERR S	29.909	15	1.994		
ERR TS	88.646	45	1.970		
ERR FS	61.314	15	4.088		
ERR TFS	101.294	45	2.251		
ERR D	73.710	30	2.450		
ERR TD	72.911	90	0.810		
ERR FD	27.355	30	0.912		
ERR TFD	77.873	90	0.865		
ERR SD	35.340	30	1.178		
ERR TSD	78.250	90	0.869		
ERR FSD	33.882	30	1.129		
ERR TFSD	64.277	90	0.714		
TOTAL	2479.933	767			

* P < .05
** P < .01

Table C-5. Peripheral cues and color - experiment #2 at longitude = 12,6,&3 thousand feet - dependant variable = power lever angle on engine #2.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FIELD OF V	2
S	SCENE COMP	2
P	PILOTS	16
D	DISTANCE	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	78.726	3	26.242	F(3,45) =	1.91, P = 0.142
F	29.760	1	29.760	F(1,15) =	1.45, P = 0.246
TF	85.009	3	28.336	F(3,45) =	1.89, P = 0.145
S	9.166	1	9.166	F(1,15) =	0.86, P = 0.367
TS	48.443	3	16.104	F(3,45) =	1.55, P = 0.214
FS	[illegible]	1	83.791	F(1,15) =	5.99, P = 0.027 *
TFS	46.917	3	15.639	F(3,45) =	1.27, P = 0.296
P	4315.060	15			
D	442.149	2	221.074	F(2,30) =	16.96, P = 0.000 **
TD	37.539	6	6.257	F(6,90) =	0.66, P = 0.685
FD	22.615	2	11.308	F(2,30) =	0.94, P = 0.401
TFD	75.436	6	12.573	F(6,90) =	1.61, P = 0.153
SD	2.496	2	1.248	F(2,30) =	0.11, P = 0.892
TSD	93.862	6	15.644	F(6,90) =	1.83, P = 0.102
FSD	18.751	2	9.375	F(2,30) =	0.63, P = 0.541
TFSD	38.135	6	6.356	F(6,90) =	0.79, P = 0.583
ERR T	619.819	45	13.774		
ERR F	306.001	15	20.400		
ERR TF	539.633	45	11.992		
ERR S	159.498	15	10.633		
ERR TS	467.952	45	10.399		
ERR FS	179.867	15	11.991		
ERR TFS	554.154	45	12.315		
ERR D	391.147	30	13.038		
ERR TD	858.148	90	9.535		
ERR FD	360.479	30	12.016		
ERR TFD	705.304	90	7.836		
ERR SD	447.839	30	14.928		
ERR TSD	419.974	90	4.666		
ERR FSD	448.935	30	14.964		
ERR TFSD	727.734	90	8.086		
TOTAL	13417.437	767			

* P < .05
** P < .01

Table C-6. Peripheral cues and color - experiment #2 - touchdown data - lateral deviation.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FOV	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	220.293	3	73.431	F(3,45) =	0.14, P = 0.934
F	2049.448	1	2049.448	F(1,15) =	2.63, P = 0.126
TF	1481.439	3	493.813	F(3,45) =	0.68, P = 0.571
S	5741.219	1	5741.219	F(1,15) =	5.27, P = 0.037 *
TS	2535.751	3	845.250	F(3,45) =	1.49, P = 0.231
FS	1471.042	1	1471.042	F(1,15) =	1.74, P = 0.206
TFS	1215.678	3	405.226	F(3,45) =	0.55, P = 0.650
P	82170.246	15			
ERR T	23252.895	45	516.731		
ERR F	11701.309	15	780.087		
ERR TF	32861.165	45	730.248		
ERR S	16350.371	15	1090.025		
ERR TS	25592.019	45	568.712		
ERR FS	12651.465	15	843.431		
ERR TFS	33110.170	45	735.782		
TOTAL	252404.517	255			

* P < .05
** P < .01

Table C-7. Peripheral cues and color - experiment #2 - touchdown data - pitch angle rate.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
F	FOV	2
S	SCENE COMP	2
P	PILOTS	16

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	1.568	3	0.523	F(3,45) =	0.67, P = 0.576
F	0.803	1	0.803	F(1,15) =	1.06, P = 0.320
TF	2.713	3	0.904	F(3,45) =	1.48, P = 0.232
S	1.144	1	1.144	F(1,15) =	1.48, P = 0.242
TS	7.211	3	2.404	F(3,45) =	3.51, P = 0.021 *
FS	0.239	1	0.239	F(1,15) =	0.39, P = 0.542
TFS	1.006	3	0.335	F(3,45) =	0.43, P = 0.735
P	9.727	15			
ERR T	35.231	45	0.783		
ERR F	11.375	15	0.758		
ERR TF	27.436	45	0.610		
ERR S	11.587	15	0.772		
ERR TS	30.781	45	0.684		
ERR FS	9.192	15	0.613		
ERR TFS	35.423	45	0.787		
TOTAL	185.437	255			

* P < .05
** P < .01

Table C-8. Peripheral cues and color - experiment #2 at long = 12,6,&3KFT - dependent variable = pitch angle rate.

LABEL	FACTOR	NO. LEVELS
R	REPLICATIO	4
F	FIELD OF V	2
C	SCENE COMP	2
P	PILOTS	16
D	DISTANCE F	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	0.42	3	0.14	F(3,45) =	0.81, P = 0.493
F	0.31	1	0.31	F(1,15) =	1.86, P = 0.193
RF	0.15	3	0.05	F(3,45) =	0.29, P = 0.829
C	0.02	1	0.02	F(1,15) =	0.05, P = 0.826
RC	0.96	3	0.32	F(3,45) =	2.01, P = 0.126
FC	0.06	1	0.06	F(1,15) =	0.40, P = 0.536
RFC	0.45	3	0.15	F(3,45) =	0.93, P = 0.436
P	5.86	15			
D	0.53	2	0.26	F(2,30) =	0.83, P = 0.446
RD	1.26	6	0.21	F(6,90) =	1.40, P = 0.194
FD	2.77	2	1.39	F(2,30) =	4.91, P = 0.014 *
RFD	0.85	6	0.14	F(6,90) =	0.67, P = 0.672
CD	1.25	2	0.62	F(2,30) =	4.21, P = 0.025 *
RCD	1.16	6	0.19	F(6,90) =	1.15, P = 0.341
FCD	0.03	2	0.01	F(2,30) =	0.09, P = 0.916
RFCD	1.27	6	0.21	F(6,90) =	1.12, P = 0.360
ERR R	7.70	45	0.17		
ERR F	2.47	15	0.16		
ERR RF	7.70	45	0.17		
ERR C	4.96	15	0.33		
ERR RC	7.13	45	0.16		
ERR FC	2.24	15	0.15		
ERR RFC	7.30	45	0.16		
ERR D	9.54	30	0.32		
ERR RD	12.82	90	0.14		
ERR FD	8.46	30	0.28		
ERR RFD	18.93	90	0.21		
ERR CD	4.45	30	0.15		
ERR RCD	15.13	90	0.17		
ERR FCD	5.07	30	0.17		
ERR RFCD	17.02	90	0.19		
TOTAL	148.36	767			

* P < .05
** P < .01

APPENDIX D

ANALYSIS OF VARIANCE SUMMARY TABLES FOR EXPERIMENT #3

Table D-1. Peripheral cues and color - experiment #3 at distance from touchdown mark = 15190 feet - dependent variable = altitude above terrain of aircraft center of gravity.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTEN	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	71820.497	3	23940.166	F(3,36) =	4.62, P = 0.008 **
A	406.680	1	406.680	F(1,12) =	0.03, P = 0.857
RA	5808.766	3	1936.255	F(3,36) =	0.44, P = 0.728
S	13537.066	1	13537.066	F(1,12) =	1.17, P = 0.300
RS	50152.369	3	16717.456	F(3,36) =	3.01, P = 0.043 *
AS	975.455	1	975.455	F(1,12) =	0.21, P = 0.655
RAS	36903.821	3	12301.274	F(3,36) =	1.36, P = 0.265
C	82334.648	2	41167.324	F(2,12) =	0.72, P = 0.508
RC	44958.945	6	7493.157	F(6,36) =	1.45, P = 0.224
AC	7045.829	2	3522.911	F(2,12) =	0.29, P = 0.752
RAC	17497.710	6	2916.285	F(6,36) =	0.66, P = 0.684
SC	34919.010	2	17459.505	F(2,12) =	1.52, P = 0.259
RSC	53435.286	6	8905.881	F(6,36) =	1.60, P = 0.175
ASC	10274.204	2	5137.102	F(2,12) =	1.11, P = 0.362
RASC	22304.702	6	3717.450	F(6,36) =	0.42, P = 0.863
ERR BETWEEN	689408.609	12	57450.717		
ERR R	186426.405	36	5178.511		
ERR A	144889.088	12	12074.091		
ERR RA	159701.159	36	4436.143		
ERR S	138276.699	12	11523.058		
ERR RS	200183.262	36	5560.646		
ERR AS	55644.433	12	4637.036		
ERR RAS	321246.547	36	8923.515		
TOTAL	2348260.989	239			

* P < .05
** P < .01

Table D-2. Peripheral cues and color - experiment #3 at distance from touchdown mark = 12150 feet - dependent variable = altitude abover terrain of aircraft center of gravity.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTEN	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	82616.00	3	27538.67	F(3,36) =	4.14, P = 0.013 *
A	4894.96	1	4894.96	F(1,12) =	0.35, P = 0.565
RA	10843.73	3	3614.58	F(3,36) =	0.83, P = 0.487
S	16376.57	1	16376.57	F(1,12) =	1.04, P = 0.328
RS	53161.33	3	17720.44	F(3,36) =	2.16, P = 0.115
AS	8497.14	1	8497.14	F(1,12) =	0.91, P = 0.359
RAS	40849.79	3	13616.60	F(3,36) =	1.29, P = 0.294
C	23061.10	2	11530.55	F(2,12) =	0.26, P = 0.774
RC	20814.69	6	3469.11	F(6,36) =	0.52, P = 0.788
AC	26129.05	2	13064.52	F(2,12) =	0.93, P = 0.421
RAC	14242.13	6	2373.69	F(6,36) =	0.54, P = 0.771
SC	47027.36	2	23513.68	F(2,12) =	1.49, P = 0.263
RSC	33310.48	6	5551.75	F(6,36) =	0.67, P = 0.672
ASC	21689.84	2	10844.92	F(2,12) =	1.16, P = 0.346
RASC	22803.02	6	3800.50	F(6,36) =	0.36, P = 0.960
ERR BETWEEN	529371.31	12	44114.28		
ERR R	239640.40	36	6656.68		
ERR A	167816.09	12	13984.67		
ERR RA	157195.57	36	4366.54		
ERR S	188787.01	12	15732.25		
ERR RS	296978.40	36	8249.40		
ERR AS	112001.99	12	9333.42		
ERR RAS	380920.60	36	10561.29		
TOTAL	2449195.63	239			

* P < .05
** P < .01

Table D-3. Peripheral cues and color - experiment #3 at distance from touchdown mark = 15190 feet - dependent variable = glideslope deviation.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	72374.386	3	24124.795	F(3,36) =	4.67, P = 0.007 **
A	466.241	1	466.241	F(1,12) =	0.03, P = 0.857
RA	5721.710	3	1907.237	F(3,36) =	0.43, P = 0.734
S	13633.648	1	13633.648	F(1,12) =	1.19, P = 0.297
RS	49886.407	3	16628.802	F(3,36) =	3.00, P = 0.043 *
AS	927.604	1	927.604	F(1,12) =	0.20, P = 0.661
RAS	36802.349	3	12267.450	F(3,36) =	1.38, P = 0.265
C	83659.231	2	41829.615	F(2,12) =	0.72, P = 0.505
RC	44749.542	6	7458.257	F(6,36) =	1.44, P = 0.225
AC	7043.720	2	3521.860	F(2,12) =	0.29, P = 0.751
RAC	17199.018	6	2866.503	F(6,36) =	0.64, P = 0.694
SC	34617.636	2	17308.818	F(2,12) =	1.51, P = 0.260
RSC	53559.754	6	8926.626	F(6,36) =	1.61, P = 0.172
ASC	10624.219	2	5312.109	F(2,12) =	1.16, P = 0.347
RASC	21794.161	6	3632.360	F(6,36) =	0.11, P = 0.869
ERR BETWEEN	692749.832	12	57729.153		
ERR R	185956.105	36	5165.447		
ERR A	144056.802	12	12004.734		
ERR RA	160266.338	36	4451.843		
ERR S	137335.294	12	11444.608		
ERR RS	199432.593	36	5539.794		
ERR AS	55023.992	12	4585.333		
ERR RAS	320795.566	36	8910.988		
TOTAL	2348615.621	239			

* P < .05
** P < .01

Table D-4. Peripheral cues and color - experiment #3 at distance from touchdown mark = 12150 feet - dependent variable = glideslope deviation.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHRONOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	82935.51	3	27645.17	F(3,36) =	4.19, P = 0.012 *
A	4995.34	1	4995.34	F(1,12) =	0.36, P = 0.561
RA	10937.93	3	3645.98	F(3,36) =	0.83, P = 0.485
S	16401.91	1	16401.91	F(1,12) =	1.04, P = 0.328
RS	53729.99	3	17910.00	F(3,36) =	2.17, P = 0.108
AS	8814.93	1	8814.93	F(1,12) =	0.94, P = 0.351
RAS	41473.92	3	13824.64	F(3,36) =	1.30, P = 0.288
C	23774.97	2	11887.48	F(2,12) =	0.27, P = 0.769
RC	20879.78	6	3479.96	F(6,36) =	0.53, P = 0.783
AC	26191.49	2	13095.75	F(2,12) =	0.94, P = 0.418
RAC	14396.83	6	2399.47	F(6,36) =	0.55, P = 0.768
SC	45953.27	2	22976.64	F(2,12) =	1.46, P = 0.271
RSC	33716.36	6	5619.39	F(6,36) =	0.68, P = 0.666
ASC	21662.80	2	10831.40	F(2,12) =	1.17, P = 0.344
RASC	22796.69	6	3799.45	F(6,36) =	0.36, P = 0.900
ERR BETWEEN	530577.26	12	44214.77		
ERR R	237287.16	36	6591.31		
ERR A	167610.12	12	13967.51		
ERR RA	157586.65	36	4377.41		
ERR S	189075.10	12	15756.26		
ERR RS	297037.25	36	8251.03		
ERR AS	112370.55	12	9364.21		
ERR RAS	382009.04	36	10611.36		
TOTAL	2502414.84	239			

* P < .05
** P < .01

Table D-5. Peripheral cues and color - experiment #3 at distance from touchdown mark = 12150 feet - dependent variable = rate of climb.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	50.10	3	16.70	F(3,36) =	1.64, P = 0.198
A	10.51	1	10.51	F(1,12) =	1.92, P = 0.192
RA	13.81	3	4.60	F(3,36) =	0.83, P = 0.484
S	9.35	1	9.35	F(1,12) =	2.32, P = 0.154
RS	10.60	3	3.53	F(3,36) =	0.48, P = 0.695
AS	48.78	1	48.78	F(1,12) =	9.58, P = 0.009 **
RAS	21.96	3	7.32	F(3,36) =	0.80, P = 0.503
C	97.84	2	48.92	F(2,12) =	2.18, P = 0.156
RC	51.84	6	8.64	F(6,36) =	0.85, P = 0.543
AC	12.48	2	6.24	F(2,12) =	1.14, P = 0.353
RAC	22.80	6	3.80	F(6,36) =	0.69, P = 0.661
SC	9.30	2	4.65	F(2,12) =	1.15, P = 0.349
RSC	33.90	6	5.65	F(6,36) =	0.77, P = 0.595
ASC	0.38	2	0.19	F(2,12) =	0.04, P = 0.964
RASC	55.02	6	9.17	F(6,36) =	1.00, P = 0.441
ERR BETWEEN	269.70	12	22.47		
ERR R	367.53	36	10.21		
ERR A	65.84	12	5.49		
ERR RA	198.81	36	5.52		
ERR S	48.45	12	4.04		
ERR RS	262.79	36	7.30		
ERR AS	61.12	12	5.09		
ERR RAS	330.41	36	9.18		
TOTAL	2053.32	239			

* $P < .05$
** $P < .01$

Table D-6. Peripheral cues and color - experiment #3 at distance from touchdown mark = 6076 feet - dependent variable = rate of climb.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	12.960	3	4.320	F(3,36) =	0.42, P = 0.741
A	16.638	1	16.638	F(1,12) =	0.93, P = 0.353
RA	39.555	3	13.185	F(3,36) =	1.74, P = 0.176
S	1.248	1	1.248	F(1,12) =	0.06, P = 0.810
RS	121.437	3	40.479	F(3,36) =	5.75, P = 0.003 **
AS	11.355	1	11.355	F(1,12) =	1.24, P = 0.287
RAS	31.850	3	10.617	F(3,36) =	0.90, P = 0.450
C	96.581	2	48.290	F(2,12) =	0.79, P = 0.476
RC	66.208	6	11.035	F(6,36) =	1.07, P = 0.400
AC	6.519	2	3.259	F(2,12) =	0.18, P = 0.835
RAC	56.122	6	9.354	F(6,36) =	1.24, P = 0.311
SC	76.243	2	38.122	F(2,12) =	1.84, P = 0.201
RSC	102.229	6	17.038	F(6,36) =	2.53, P = 0.038 *
ASC	50.275	2	25.138	F(2,12) =	2.75, P = 0.104
RASC	49.224	6	8.204	F(6,36) =	0.70, P = 0.654
ERR BETWEEN	733.814	12	61.151		
ERR R	372.170	36	10.338		
ERR A	213.582	12	17.798		
ERR RA	272.396	36	7.567		
ERR S	248.987	12	20.749		
ERR RS	253.428	36	7.040		
ERR AS	109.570	12	9.131		
ERR RAS	423.712	36	11.770		
TOTAL	3376.331	239			

* P < .05
** P < .01

Table D-7. Peripheral cues and color - experiment #3 at distance from touchdown mark = 3038 feet - dependent variable = vertical speed.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	38.219	3	12.740	F(3,36) =	0.86, P = 0.473
A	4.024	1	4.024	F(1,12) =	0.34, P = 0.569
RA	22.332	3	7.444	F(3,36) =	0.70, P = 0.558
S	0.049	1	0.049	F(1,12) =	0.00, P = 0.964
RS	125.540	3	41.847	F(3,36) =	3.61, P = 0.022 *
AS	3.526	1	3.526	F(1,12) =	0.23, P = 0.642
RAS	34.049	3	11.350	F(3,36) =	0.73, P = 0.541
C	8.337	2	4.168	F(2,12) =	0.06, P = 0.942
RC	102.066	6	17.011	F(6,36) =	1.14, P = 0.359
AC	44.768	2	22.384	F(2,12) =	1.91, P = 0.190
RAC	47.706	6	7.951	F(6,36) =	0.75, P = 0.615
SC	123.521	2	61.761	F(2,12) =	1.31, P = 0.307
RSC	113.555	6	18.926	F(6,36) =	1.63, P = 0.166
ASC	11.564	2	5.782	F(2,12) =	0.37, P = 0.696
RASC	91.739	6	15.290	F(6,36) =	0.98, P = 0.450
ERR BETWEEN	837.675	12	69.806		
ERR R	536.692	36	14.908		
ERR A	140.514	12	11.709		
ERR RA	382.415	36	10.623		
ERR S	207.405	12	17.284		
ERR RS	417.053	36	11.585		
ERR AS	186.060	12	15.505		
ERR RAS	559.238	36	15.534		
TOTAL	4394.112	239			

* P < .05
** P < .01

Table D-8. Peripheral cues and color - experiment #3 - touchdown data (T-1) - rate of climb.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
C	COLOR	2
S	SCENE COMP	2
P	PILOTS	5
G	CHRONOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	20.427	3	6.809	F(3,36) =	1.07, P = 0.376
C	1.680	1	1.680	F(1,12) =	0.50, P = 0.493
TC	17.088	3	5.696	F(3,36) =	1.09, P = 0.367
S	10.580	1	10.580	F(1,12) =	1.42, P = 0.257
TS	15.365	3	5.122	F(3,36) =	1.10, P = 0.362
CS	7.105	1	7.105	F(1,12) =	1.25, P = 0.286
TCS	14.973	3	4.991	F(3,36) =	0.99, P = 0.410
G	32.318	2	16.159	F(2,12) =	0.36, P = 0.707
TG	41.777	6	6.963	F(6,36) =	1.09, P = 0.387
CG	0.718	2	0.359	F(2,12) =	0.11, P = 0.900
TCG	44.614	6	7.436	F(6,36) =	1.42, P = 0.235
SG	3.461	2	1.730	F(2,12) =	0.23, P = 0.797
TSG	27.708	6	4.618	F(6,36) =	0.99, P = 0.446
CSG	4.613	2	2.306	F(2,12) =	0.41, P = 0.675
TCSG	91.074	6	15.179	F(6,36) =	3.00, P = 0.016 *
ERR BETWEEN	543.360	12	45.280		
ERR T	229.921	36	6.387		
ERR C	40.392	12	3.366		
ERR TC	188.844	36	5.246		
ERR S	89.616	12	7.468		
ERR TS	167.727	36	4.659		
ERR CS	68.239	12	5.687		
ERR TCS	182.035	36	5.057		
TOTAL	1043.636	239			

* P < .05
** P < .01

Table D-9. Peripheral cues and color - experiment #3 at distance from touchdown mark = 12150 feet - dependent variable = aircraft pitch angle.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	10.68	3	3.56	F(3,36) =	3.64, P = 0.022 *
A	0.02	1	0.02	F(1,12) =	0.03, P = 0.877
RA	1.45	3	0.48	F(3,36) =	0.59, P = 0.628
S	3.42	1	3.42	F(1,12) =	1.92, P = 0.191
RS	1.61	3	0.54	F(3,36) =	0.76, P = 0.524
AS	2.51	1	2.51	F(1,12) =	2.17, P = 0.166
RAS	2.16	3	0.72	F(3,36) =	0.58, P = 0.630
C	118.25	2	59.12	F(2,12) =	3.86, P = 0.051
RC	6.47	6	1.08	F(6,36) =	1.10, P = 0.381
AC	2.44	2	1.22	F(2,12) =	1.43, P = 0.277
RAC	2.05	6	0.34	F(6,36) =	0.41, P = 0.865
SC	4.32	2	2.16	F(2,12) =	1.22, P = 0.331
RSC	3.45	6	0.57	F(6,36) =	0.81, P = 0.569
ASC	0.28	2	0.14	F(2,12) =	0.12, P = 0.887
RASC	2.88	6	0.48	F(6,36) =	0.39, P = 0.882
ERR BETWEEN	103.95	12	15.33		
ERR R	35.24	36	0.98		
ERR A	10.23	12	0.85		
ERR RA	29.67	36	0.82		
ERR S	21.32	12	1.78		
ERR RS	25.51	36	0.71		
ERR AS	13.87	12	1.16		
ERR RAS	44.53	36	1.24		
TOTAL	526.12	239			

* P < .05
** P < .01

Table D-10. Peripheral cues and color - experiment #3 at distance from touchdown mark = 6076 feet - dependent variable = aircraft pitch angle.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	1.538	3	0.513	F(3,36) =	0.38, P = 0.765
A	1.076	1	1.076	F(1,12) =	0.91, P = 0.358
RA	3.019	3	1.006	F(3,36) =	1.06, P = 0.380
S	2.893	1	2.893	F(1,12) =	0.78, P = 0.395
RS	8.002	3	2.667	F(3,36) =	3.16, P = 0.036 *
AS	0.059	1	0.059	F(1,12) =	0.05, P = 0.819
RAS	2.406	3	0.802	F(3,36) =	0.56, P = 0.644
C	101.310	2	50.655	F(2,12) =	2.46, P = 0.127
RC	3.676	6	0.613	F(6,36) =	0.46, P = 0.834
AC	0.311	2	0.156	F(2,12) =	0.13, P = 0.877
RAC	4.995	6	0.832	F(6,36) =	0.87, P = 0.524
SC	32.002	2	16.001	F(2,12) =	4.31, P = 0.039 *
RSC	7.128	6	1.188	F(6,36) =	1.41, P = 0.239
ASC	2.205	2	1.102	F(2,12) =	1.02, P = 0.390
RASC	10.046	6	1.674	F(6,36) =	1.17, P = 0.343
ERR BETWEEN	246.957	12	20.580		
ERR R	48.027	36	1.334		
ERR A	14.126	12	1.177		
ERR RA	34.310	36	0.953		
ERR S	44.527	12	3.711		
ERR RS	30.426	36	0.845		
ERR AS	12.959	12	1.080		
ERR RAS	51.459	36	1.429		
TOTAL	663.451	239			

* P < .05
** P < .01 .

Table D-11. Peripheral cues and color - experiment #3 at distance from touchdown mark = 3038 feet - dependent variable = aircraft pitch angle.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	1.825	3	0.608	F(3,36) =	0.43, P = 0.73[illegible]
A	0.840	1	0.840	F(1,12) =	1.02, P = 0.332
RA	1.690	3	0.563	F(3,36) =	0.54, P = 0.660
S	7.081	1	7.081	F(1,12) =	1.60, P = 0.230
RS	13.180	3	4.393	F(3,36) =	4.08, P = 0.014 *
AS	0.161	1	0.161	F(1,12) =	0.07, P = 0.802
RAS	0.574	3	0.191	F(3,36) =	0.19, P = 0.899
C	85.646	2	42.823	F(2,12) =	1.84, P = 0.200
RC	9.106	6	1.518	F(6,36) =	1.07, P = 0.399
AC	8.509	2	4.255	F(2,12) =	5.18, P = 0.024 *
RAC	6.737	6	1.123	F(6,36) =	1.07, P = 0.399
SC	36.065	2	18.033	F(2,12) =	4.08, P = 0.045 *
RSC	4.710	6	0.785	F(6,36) =	0.73, P = 0.629
ASC	0.608	2	0.304	F(2,12) =	0.12, P = 0.885
RASC	9.915	6	1.652	F(6,36) =	1.66, P = 0.154
ERR BETWEEN	278.634	12	23.220		
ERR R	51.087	36	1.419		
ERR A	9.857	12	0.821		
ERR RA	37.823	36	1.051		
ERR S	53.085	12	4.424		
ERR RS	38.717	36	1.075		
ERR AS	29.500	12	2.458		
ERR RAS	35.390	36	0.983		
TOTAL	720.747	239			

* $P < .05$
** $P < .01$

Table D-12. Peripheral cues and color - experiment #3 at distance from touchdown = 15190 feet - dependent variable = pitch angle rate.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE CONT	2
P	PILOTS	5
C	CHRONOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES			
R	0.105	3	0.035	F(3,36) =	0.66, P = 0.580	
A	0.014	1	0.014	F(1,12) =	0.23, P = 0.642	
RA	0.486	3	0.162	F(3,36) =	3.32, P = 0.031	*
S	0.003	1	0.003	F(1,12) =	0.03, P = 0.867	
RS	0.466	3	0.155	F(3,36) =	2.04, P = 0.126	
AS	0.033	1	0.033	F(1,12) =	0.44, P = 0.519	
RAS	0.136	3	0.045	F(3,36) =	0.65, P = 0.591	
C	0.031	2	0.016	F(2,12) =	0.27, P = 0.770	
RC	0.252	6	0.042	F(6,36) =	0.79, P = 0.583	
AC	0.387	2	0.193	F(2,12) =	3.05, P = 0.085	
RAC	0.322	6	0.054	F(6,36) =	1.10, P = 0.383	
SC	0.125	2	0.063	F(2,12) =	0.70, P = 0.515	
RSC	0.379	6	0.063	F(6,36) =	0.83, P = 0.557	
ASC	0.291	2	0.146	F(2,12) =	1.92, P = 0.189	
RASC	0.380	6	0.063	F(6,36) =	0.85, P = 0.539	
ERR BETWEEN	0.702	12	0.058			
ERR R	1.907	36	0.053			
ERR A	0.760	12	0.063			
ERR RA	1.759	36	0.049			
ERR S	1.073	12	0.089			
ERR RS	2.749	36	0.076			
ERR AS	0.911	12	0.076			
ERR RAS	2.530	36	0.070			
TOTAL	15.784	239				

* P < .05
** P < .01

Table D-13. Peripheral cues and color - experiment #3 at distance from touchdown mark = 12150 feet - dependent variable = pitch angle rate.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE COMP	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	0.05	3	0.02	F(3,36) =	0.21, P = 0.892
A	0.17	1	0.17	F(1,12) =	2.15, P = 0.168
RA	0.06	3	0.02	F(3,36) =	0.26, P = 0.852
S	0.07	1	0.07	F(1,12) =	0.91, P = 0.360
RS	1.04	3	0.35	F(3,36) =	4.54, P = 0.008 **
AS	0.13	1	0.13	F(1,12) =	3.63, P = 0.081
RAS	0.21	3	0.07	F(3,36) =	0.56, P = 0.643
C	0.32	2	0.16	F(2,12) =	1.99, P = 0.179
RC	1.65	6	0.27	F(6,36) =	3.13, P = 0.014 *
AC	0.04	2	0.02	F(2,12) =	0.27, P = 0.770
RAC	1.15	6	0.19	F(6,36) =	2.67, P = 0.038 *
SC	0.12	2	0.06	F(2,12) =	0.72, P = 0.505
RSC	0.71	6	0.12	F(6,36) =	1.56, P = 0.188
ASC	0.17	2	0.09	F(2,12) =	2.37, P = 0.135
RASC	0.21	6	0.03	F(6,36) =	0.26, P = 0.944
ERR BETWEEN	0.97	12	0.08		
ERR R	3.16	36	0.09		
ERR A	0.97	12	0.08		
ERR RA	2.58	36	0.07		
ERR S	0.97	12	0.08		
ERR RS	2.74	36	0.08		
ERR AS	0.43	12	0.04		
ERR RAS	4.52	36	0.13		
TOTAL	22.47	239			

* $P < .05$
** $P < .01$

Table D-14. Peripheral cues and color - experiment #3 at distance from touchdown mark = 6076 feet - dependent variable = pitch angle rate.

LABEL	FACTOR	NO. LEVELS
R	REPETITION	4
A	AREA COLOR	2
S	SCENE CONT	2
P	PILOTS	5
C	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
R	0.309	3	0.103	F(3,36) =	0.68, P = 0.569
A	0.069	1	0.069	F(1,12) =	0.44, P = 0.519
RA	0.240	3	0.080	F(3,36) =	0.61, P = 0.614
S	0.193	1	0.193	F(1,12) =	1.48, P = 0.247
RS	0.303	3	0.101	F(3,36) =	1.05, P = 0.382
AS	0.199	1	0.199	F(1,12) =	7.07, P = 0.021 *
RAS	0.211	3	0.070	F(3,36) =	0.65, P = 0.591
C	0.736	2	0.368	F(2,12) =	3.20, P = 0.074
RC	0.283	6	0.047	F(6,36) =	0.31, P = 0.927
AC	0.489	2	0.245	F(2,12) =	1.31, P = 0.306
RAC	0.706	6	0.117	F(6,36) =	0.89, P = 0.515
SC	0.136	2	0.068	F(2,12) =	0.52, P = 0.607
RSC	0.817	6	0.136	F(6,36) =	1.42, P = 0.234
ASC	1.142	2	0.571	F(2,12) =	20.33, P = 0.000 **
RASC	0.622	6	0.104	F(6,36) =	0.95, P = 0.473
ERR BETWEEN	1.353	12	0.113		
ERR R	5.443	36	0.151		
ERR A	1.878	12	0.157		
ERR RA	4.737	36	0.132		
ERR S	1.564	12	0.130		
ERR RS	3.454	36	0.096		
ERR AS	0.337	12	0.028		
ERR RAS	3.932	36	0.109		
TOTAL	29.067	239			

* P < .05
** P < .01

Table D-15. Peripheral cues and color - experiment #3 - touchdown data (T-1) - true airspeed.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
C	COLOR	2
S	SCENE COMP	2
P	PILOTS	5
G	CHRONOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	151.863	3	50.621	F(3,36) =	1.43, P = 0.250
C	316.879	1	316.879	F(1,12) =	4.36, P = 0.059
TC	163.031	3	54.344	F(3,36) =	1.83, P = 0.160
S	218.026	1	218.026	F(1,12) =	0.85, P = 0.376
TS	155.512	3	51.837	F(3,36) =	0.93, P = 0.436
CS	13.895	1	13.895	F(1,12) =	0.09, P = 0.767
TCS	82.550	3	27.517	F(3,36) =	0.80, P = 0.504
G	741.687	2	370.844	F(2,12) =	0.36, P = 0.703
TG	308.006	6	51.334	F(6,36) =	1.45, P = 0.223
CG	131.986	2	65.993	F(2,12) =	0.91, P = 0.430
TCG	290.041	6	48.340	F(6,36) =	1.63, P = 0.168
SG	1428.785	2	714.392	F(2,12) =	2.77, P = 0.103
TSG	76.912	6	12.819	F(6,36) =	0.23, P = 0.964
CSG	24.334	2	12.167	F(2,12) =	0.08, P = 0.923
TCSG	29.433	6	4.905	F(6,36) =	0.14, P = 0.989
ERR BETWEEN	12280.207	12	1023.351		
ERR T	1275.376	36	35.427		
ERR C	872.755	12	72.730		
ERR TC	1070.496	36	29.736		
ERR S	3094.435	12	257.870		
ERR TS	2006.663	36	55.741		
ERR CS	1819.513	12	151.626		
ERR TCS	1243.140	36	34.532		
TOTAL	27795.525	239			

* P < .05
** P < .01

Table D-16. Peripheral cues and color - experiment #3 - touchdown data (T-1) - Distance from glideslope intercrpt.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
C	COLOR	2
S	SCENE COMP	2
P	PILOTS	5
G	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES			
T	289939.146	3	96646.382	F(3,36) =	0.19, P = 0.902	
C	605914.504	1	605914.504	F(1,12) =	5.54, P = 0.036	*
TC	52763.546	3	17587.849	F(3,36) =	0.04, P = 0.987	
S	2613132.704	1	2613132.704	F(1,12) =	3.35, P = 0.092	
TS	1081552.212	3	360517.404	F(3,36) =	0.75, P = 0.527	
CS	817.704	1	817.704	F(1,12) =	0.00, P = 0.967	
TCS	801953.146	3	267317.715	F(3,36) =	0.77, P = 0.518	
G	13578532.508	2	6789266.254	F(2,12) =	1.18, P = 0.340	
TG	4143783.692	6	690630.615	F(6,36) =	1.36, P = 0.258	
CG	2145839.908	2	1072919.954	F(2,12) =	9.81, P = 0.003	**
TCG	3366521.892	6	561086.982	F(6,36) =	1.43, P = 0.230	
SG	1292512.058	2	646256.029	F(2,12) =	0.83, P = 0.460	
TSG	1574525.075	6	262420.846	F(6,36) =	0.55, P = 0.767	
CSG	275398.658	2	137699.329	F(2,12) =	0.31, P = 0.741	
TCSG	1705277.142	6	284212.857	F(6,36) =	0.82, P = 0.563	
ERR BETWEEN	68989418.700	12	5749118.225			
ERR T	18297570.100	36	508265.836			
ERR C	1311872.150	12	109322.679			
ERR TC	14120277.250	36	392229.924			
ERR S	9366321.300	12	780526.775			
ERR TS	17200878.900	36	477802.192			
ERR CS	5382460.950	12	448538.412			
ERR TCS	12493964.650	36	347054.574			
TOTAL	180691627.896	239				

* P < .05
** P < .01

Table D-17. Peripheral cues and color - experiment #3 - touchdown data (adjusted) - distance from touchdown goal.

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
C	COLOR	2
S	SCENE COMP	2
P	PILOTS	5
G	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	218555.943	3	72851.981	F(3,36) =	0.14, P = 0.933
C	629594.064	1	629594.064	F(1,12) =	5.17, P = 0.042 *
TC	13378.910	3	4459.637	F(3,36) =	0.01, P = 0.998
S	2593396.989	1	2593396.989	F(1,12) =	3.44, P = 0.088
TS	1033259.870	3	344419.957	F(3,36) =	0.72, P = 0.547
CS	25.363	1	25.363	F(1,12) =	0.00, P = 0.994
TCS	827054.950	3	275684.983	F(3,36) =	0.77, P = 0.516
G	13590960.194	2	6795480.097	F(2,12) =	1.17, P = 0.344
TG	3930770.272	6	655128.379	F(6,36) =	1.29, P = 0.286
CG	2198742.424	2	1099371.212	F(2,12) =	9.03, P = 0.004 **
TCG	3403995.044	6	567332.541	F(6,36) =	1.15, P = 0.223
SG	1273845.120	2	636922.560	F(2,12) =	0.85, P = 0.453
TSG	1489582.296	6	248263.716	F(6,36) =	0.52, P = 0.790
CSG	304102.328	2	152051.164	F(2,12) =	0.34, P = 0.720
TCSG	1658411.838	6	276401.973	F(6,36) =	0.78, P = 0.594
ERR BETWEEN	69921025.362	12	5826752.113		
ERR T	18253894.429	36	507052.512		
ERR C	1461432.449	12	121786.037		
ERR TC	14087761.514	36	391326.709		
ERR S	9035441.004	12	752953.417		
ERR TS	17235554.026	36	478765.390		
ERR CS	5413471.853	12	451122.821		
ERR TCS	12822499.321	36	356180.537		
TOTAL	181396751.523	239			

* P < .05
** P < .01

Table D-18. Peripheral cues and color - experiment #3 - touchdown data (T-1) - vertical deviation from glideslope (adjusted).

LABEL	FACTOR	NO. LEVELS
T	TRIALS	4
C	COLOR	2
S	SCENE COMP	2
P	PILOTS	5
G	CHROMOSTER	3

SOURCE OF VARIATION	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES		
T	486.083	3	162.028	F(3,36) =	0.14, P = 0.933
C	1400.258	1	1400.258	F(1,12) =	5.17, P = 0.042 *
TC	29.756	3	9.919	F(3,36) =	0.01, P = 0.998
S	5767.885	1	5767.885	F(1,12) =	3.44, P = 0.088
TS	2298.038	3	766.013	F(3,36) =	0.72, P = 0.547
CS	0.056	1	0.056	F(1,12) =	0.00, P = 0.994
TCS	1839.424	3	613.141	F(3,36) =	0.77, P = 0.516
G	30227.186	2	15113.593	F(2,12) =	1.17, P = 0.344
TG	8742.291	6	1457.048	F(6,36) =	1.29, P = 0.286
CG	4890.147	2	2445.074	F(2,12) =	9.03, P = 0.004 **
TCG	7570.708	6	1261.785	F(6,36) =	1.45, P = 0.223
SG	2833.115	2	1416.558	F(2,12) =	0.85, P = 0.453
TSG	3312.928	6	552.155	F(6,36) =	0.52, P = 0.790
CSG	676.343	2	338.172	F(2,12) =	0.34, P = 0.720
TCSG	3688.417	6	614.736	F(6,36) =	0.78, P = 0.594
ERR BETWEEN	155508.944	12	12959.079		
ERR T	40597.849	36	1127.718		
ERR C	3250.321	12	270.860		
ERR TC	31332.105	36	870.336		
ERR S	20095.413	12	1674.618		
ERR TS	38333.032	36	1064.806		
ERR CS	12039.921	12	1003.327		
ERR TCS	28518.079	36	792.169		
TOTAL	403438.271	239			

* P < .05
** P < .01